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THE MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE (MCES): APPLICATIONS OF AND EXPANSION TO C3 ARCHITECTURAL EVALUATION

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MCES was developed as a tool to evaluate C2 systems architectures; more specifically, for the systematic comparison of C2 and C3 architectures. It is a methodology which may be used for evaluation, employing a common structured treatment. The methodology assumes that capabilities of selected C2 systems can be greatly improved by focussing upon both system and procedural changes. By using seven structured steps, a decisionmaker can choose to utilize recommendations made based on information provided to the process, or resubmit to the system for further analysis. Although this evaluation tool is generic in nature, its structure is such that it can be applied to a myriad of systems to study their effectiveness.

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ABSTRACT

The approach taken in this study was to imbed a previously explored information based paradigm, called the C2 Process Model, in a broader framework, the Modular Command and Control Evaluation Structure (MCES). The detailed study involved the application of all modules of the MCES. Several other applications of the MCES applied as many of the modules as were relevant.

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PREFACE

The intent of consolidating the methodological and developmental gains of the analytic community in the MCES brought this effort to the Naval Postgraduate School (NPS) at Monterey, CA. The Organization of the Joint Chiefs of Staff (OJCS), C3S, were the primary sponsors in effecting this move. The move allowed the NPS to serve as the base of operations from which the Principal Investigator, Dr. Ricki Sweet, could synthesize the work being done and could start the validation using a set of application studies.

The work of three of the Joint C3 Academic Group graduates is incorporated in the problem areas reported herein. Not only during the period of their stay at NPS, but also repeatedly since, Maj. Pat Gandee, Capt. Kevin Briggs and Capt. Ingabee Stone (all USAF) have provided support toward the continuation of the MCES effort.

In addition, the MCES was briefed to NPS students and faculty, at various stages of its development.

Animated discussions of its implications and derivatives into a wide variety of potential applications ensued. Several graduates, specifically, Lt. Bruce Nagy (USN), Lt. Liese Kennedy (USN), and Capt. Frank Prautzsch (USA), have taken these insights to their next duty assignment with the intention and opportunity to continue their use.

Further, five new students have been working with the principal investigator to expand the earlier work and to add new problem areas to the library of application studies being created. Capt. Gail Kramer (USAF) and Lt. Colleen Forster (USN) have been working in the area of the Strategic Defense Initiative (SDI), employing the MCES to further define relevant measures in the BM/C3 area. Capt. Larry Moss (USA) has been continuing Maj. Gandee's work on the IFFN (Identification Friend, Foe, or Neutral) testbed. Maj. Nick Hoffer (USMC) has been developing an acquisition application in the JTIDs area for the Marine Corps. Finally, Lt. Mary Russo (USN) has been using the MCES to gain perspective in the complex world of C3 countermeasures (C3CM).

The Joint C3 Academic Group at NPS was particularly supportive of this effort. However, among its members, Maj. Tom Brown (USAF) made extraordinary contributions to the students, staff, and especially the Principal Investigator.

His creative graphics clarified the representation of the concepts with which the MCES dealt, which until then were quite nebulous. Further, his background at the IFFN testbed was particularly helpful for technical orientation in that aspect of the research.

Lois Brunner, senior technical staff at NPS, provided substantive support in guidance to the students, theoretical mathematics and computer support of C3, and the considerable logistics of acquisition and subcontracting.

NPS offered an exceptional forum from which to interact. As a result of this contract, together with the travel support available under this contract, the MCES was briefed to high level decision-makers representing Joint Tactical Command Control and Communications Agency (JTC3A), Office of the Secretary of Defense (OSD), Office of the Secretary of the Navy (OSN), Space and Naval Warfare Systems Command (SPAWAR), Naval Oceans Systems Center (NOSC), Joint Directors of Laboratories (JDL), OJCS, Air Force Operational Test and Evaluation Center (AFOTEC), JTF IFFN Testbed, AF/SDI, AF/SA and a wide variety of other government agencies. We understand that many of the MCES foci will be used by these agencies to expedite their evaluations of C2 systems and architectures.

The impact of these application studies has expanded the utility of the relatively small funding base extensively.

All of these interactions, the involvement of students, and indeed the theoretical perspective underlying much of the MCES were made possible through the professional interest of Prof. Michael G. Sovereign, Chairman of the Joint C3 Academic Group at NPS. His early support in hosting the 1985 Workshop has expanded through the years as he has been in the forefront of enlarging the MCES usefulness to DOD.

The Department of Defense (DOD) contractor environment has also supported and accepted the MCES concepts. MacDonald Douglas - Washington Studies and Analysis Group, United Technologies, System Planning Corporation, Falcon Associates, and Alphatech were among the support contractors briefed. In the ensuing debate, many of the original concepts were expanded to incorporate newly shared insights.

Finally, two other academic institutions should be noted. Both Massachusetts Institute of Technology, specifically the

Laboratory for Information and Decision Sciences, and National Defense University, have provided free exchange and interest in the work set forth herein.

It is important that a word be said here about cosponsors and their role in this research.

First, the Naval Air Development Center, NADC, has sponsored a separate SDI-related effort described above. As a result of that effort, there has been extensive interaction with Alphatech, NADC and SDI as well as with the MITRE Corporation and AFSC/ESD/SDI. As has been the case in all other MCES related interactions, the exchanges provided "theory" expansion and elaboration.

The second outside sponsor was the Naval Surface Weapons Center, NSWC. Not only financial but outstanding technical and analytic support was provided by Dennis Mensh. His use of the MCES resulted in analytic conclusions which contributed greatly to MCES development. Three separate studies, one for the Electro-Optics Association, one for ONR/MIT and the third reported both to NSWC and in this report, were conducted jointly as a result of this effort. In addition, SPAWAR, OSN and NOSC particularly benefited from briefings of this work. This truly synergistic effort has by itself expanded the productivity of this effort many fold.

As usual the continuing cadre of experts from the community has provided yeoman service to the communication of these results. Specifically, the review of the last draft by Prof. Michael G. Sovereign, Dr. Harold Glazer of The MITRE Corporation and the COTR, Dr. John Dockery are to be noted.

INTRODUCTION

"There is a lack of analytic definition as to what a C2 architecture is. There is a need as well as a requirement for generic tools to evaluate C2 systems and architectures. Such tools as do exist are usually focused upon the specific aspects that the analyst doing the problem is most comfortable with; regardless of their fit to the problem."

It was from such a perspective that the sponsor of this research formulated this broad study effort. In fact the perspective readily translates into a firm requirement. Build a tool for the systematic comparison of C2/C3 architectures.

The Modular Command and Control Evaluation Structure (MCES) addresses this requirement. Figure 1 displays the MCES structure. This report provides an introduction to the MCES and traces its application to a number of real problems.

The MCES may be viewed as:

(1) A structure to direct the evaluation of C2 architectures;

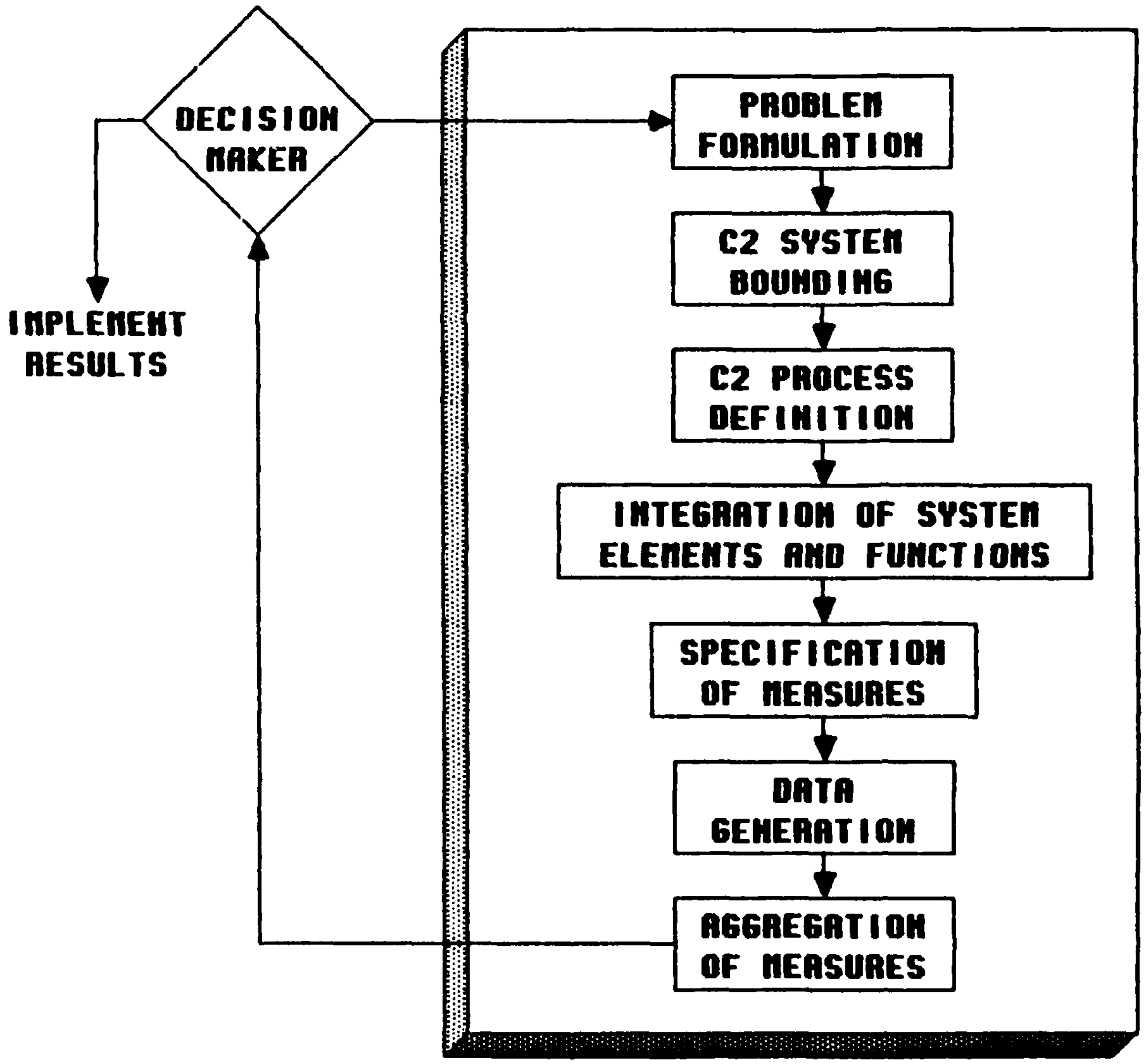


FIGURE 1

MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE (MCES)

(2) A paradigm to select and integrate from among existing tools; and, finally,

(3) A methodology which itself may be used for evaluation, employing a common structured treatment.

The JCS C3S Initiative's objective was to provide a simple yet powerful paradigm with which to evaluate alternative C2 architectures. The first step was the development of the MCES Modules to be used by staff officers tasked with evaluation of C2/C3 systems/architectures. For example, a critical, if not the critical Module, was the C2 Process. The information processing model adopted was then to be built into the MCES. At this time, there are three alternatives for this component, described below. The second step is test and implementation. This report focuses primarily on step two.

The evolving methodology assumes that capabilities of selected C2 systems can be greatly improved by focussing upon both system and procedural changes. The plan was to assess the effectiveness of a specific system through a detailed evaluation of its C2/C3 architecture. This single detailed study was intended as a demonstration of principal. In addition, other applications of the paradigm were to be scoped for subsequent study.

These evaluation plans were intended as a test of the limits to the generalizability of the MCES.

For the purposes of this initiative, "architecture" is defined as "an integrated set of systems whose physical entities, structure and functionality are coherently related". Given the current state of semantic ambiguity, this operational definition can tentatively be accepted in lieu of a more inclusive and descriptive one. So defined, "architecture" extends a commonly accepted, JCS Pub #1 based operational definition of a (C2) system. Sharing this common terminology allows direct application of the established MCES methodology to actual and proposed architectural problems. (It should be noted that , as with effectiveness measures, the term "architecture" may be considered to apply to broad principles in many different types of applications. Further, based upon this definition, unless otherwise specified, the term "system" can also be read as "system/architecture".)

THE MCES METHODOLOGY

OVERVIEW

The MCES consists of two components:

(1) A managerial system. This is a guide to specifying the problem to be analyzed. It expedites the systematic specification of the problem by focussing on identified essential characteristics of C2 systems. It alleviates the burden on decision and policy making resources by reducing the time and personnel needed both in the specification and the analysis of the problem.

(2) An analytic system. This is a guide to the analysis process itself. It permits a senior analyst to drive a C2 evaluation efficiently to a concise conclusion and provides the supporting data for decision-making. The MCES supports the analysis process through a set of standardized procedures which allow the resolution of commonly occurring analytic problems via pragmatic, established techniques.

THE MODULES

MODULE 1: PROBLEM FORMULATION

This Module requires a description of the decision-maker's analysis objectives from the standpoint of

(1) the life cycle of a military (C2) system, and

(2) the level of analysis prescribed.

The implementation of this module results in a more precise statement of the problem being addressed. Both the appropriate threat, operational and deployment concepts, and other environmental factors, the scenarios and the assumptions underlying the evaluation are made explicit.

MODULE 2: C2 SYSTEM BOUNDING

The problem statement output by Module 1 is then used in the second Module to bound the C2 system of interest. A three dimensional definition of a C2 system is employed, based on JCS Publications 1 and 2, i.e., a C2 system consists of

(1) physical entities, (equipment, software, people and their associated facilities),

(2) structure (organization, concepts of operation (including procedures and protocols and information flow patterns), and

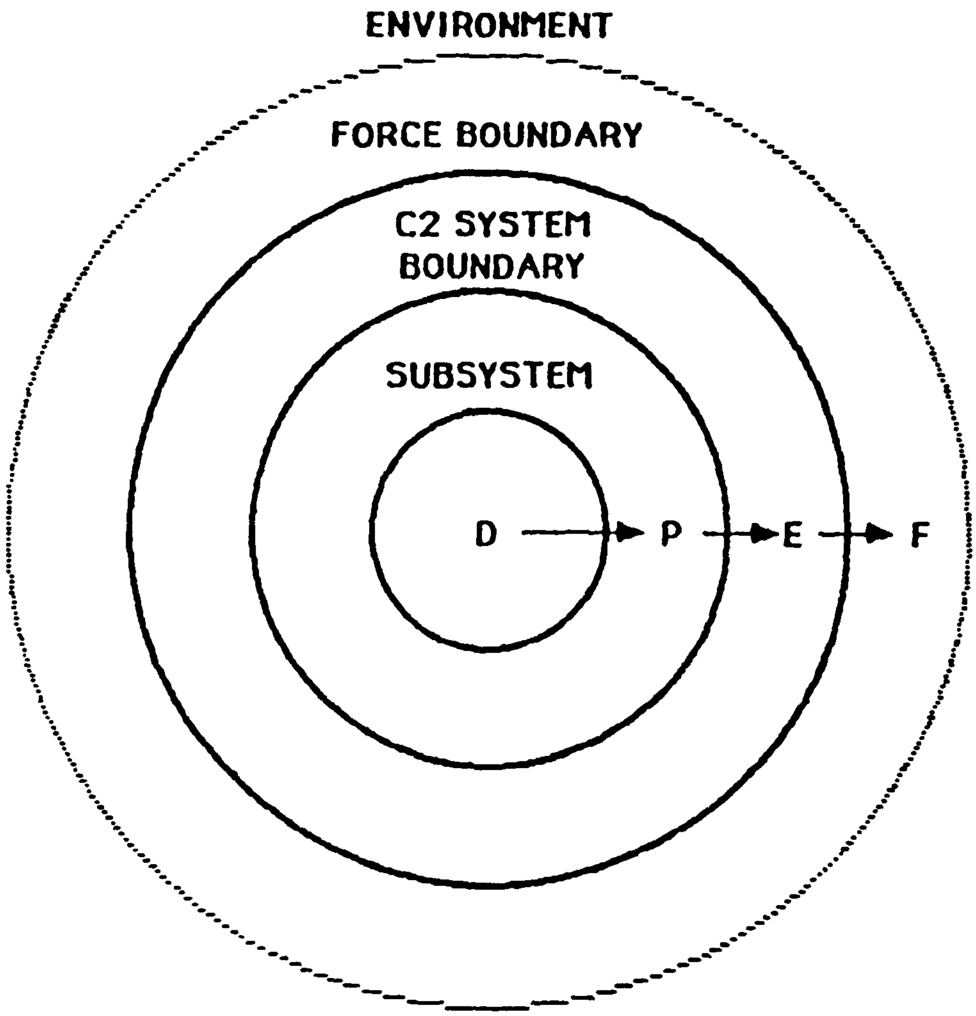
(3) (C2) process (the functionality or "what the system is doing").

This definition can be related to a graphic representation, of the levels of analysis, which the MCES represents as an "onion skin", see Figure 2. This Module focuses on the first two of the system definition components: physical entities and structure.

As a result of implementing this module, the system elements of the problem are identified and categorized.

MODULE 3: C2 PROCESS DEFINITION

A generic C2 process component for C3 systems is applied as a reference in the third Module. It forces attention on



WHERE:
D = DIMENSION
P = PERFORMANCE
E = EFFECTIVENESS
F = FORCE OUTCOME

FIGURE 2

MODULE 2: C2 SYSTEM BOUNDING

(1) the environmental "initiator" of the C2 process, which results from a change from the desired state;

(2) the internal C2 process functions that characterize what the system is doing, (sense, assess, generate, select, plan, and direct); and

(3) the input to and output from the internal C2 process.

A note on element (2) of the foregoing is in order. Although the focus of the 1985 MCES Workshop Working Group was upon the C2 Conceptual Process Model, subsequent work with this model explicitly debated this orientation. For example, plan may be seen as the first activity in the C2 Process. Plan may also be referred to as the "pre-real-time" activity of command and control.

As a result of the implementation of this module, the functions of the C2 process for a given problem are identified and mapped to the generic simplified C2 process loop, as shown in Figure 3.

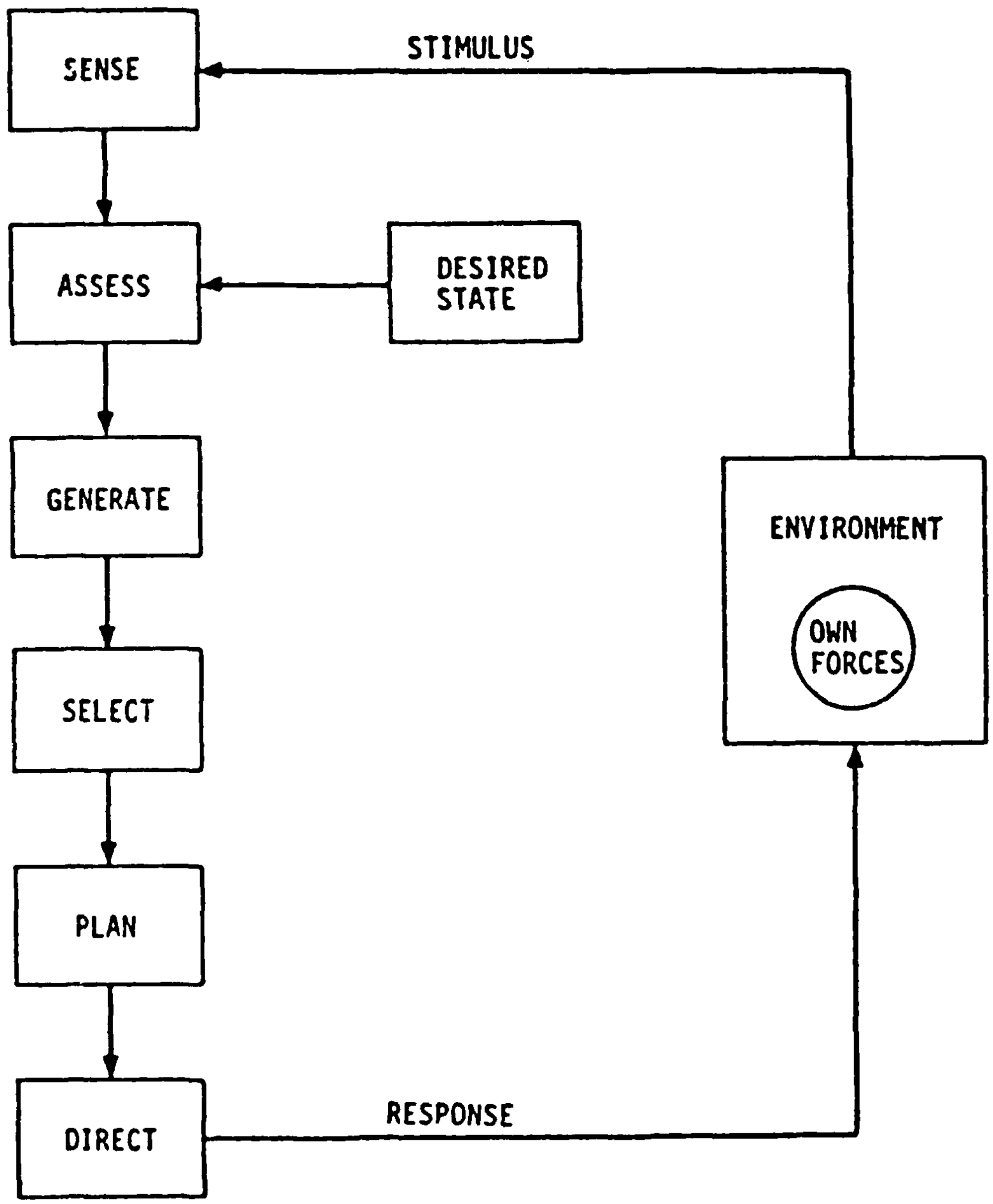


FIGURE 3

MODULE 3: GENERIC C2 PROCESS

MODULE 4: INTEGRATION OF STATICS AND DYNAMICS

The fourth Module relates the C2 processes, physical entities and structure. Techniques such as Data Flow Diagrams (DFDs) or Petri Nets may be used to show information flow through the C2 process model. (Figure 4 shows a matrix that has been found useful in integrating the three components and relating them to a hierarchical view of systems, i.e. ranging from elements to architectures.)

As an example of a technology that has been productive in his Module, consider the DFDs in some more detail. There, the input/output relationships describe the internal information flow between separate process functions, as required to perform the mission at hand. Then, the hierarchical relationships between the individual C2 functions are determined. Thus, a hierarchical "structure" in terms of the information flow between functions within the C2 process is defined. This produces an organizational structure, which could reside in a single node or be distributed between command nodes or between command and weapon nodes. Thereafter, those physical entities (man and/or machine), which perform functions are mapped to the output from the functions.

	STATICS		DYNAMICS
	PHYSICAL ENTITIES	STRUCTURE	PROCESS
ELEMENTS SUBSYSTEM SYSTEM ARCHITECTURE			

FIGURE 4

MODULE 4: INTEGRATION OF STATICS AND DYNAMICS

The C2 process internal processing may be documented, specifying how the information is input and output from the function.

The result of this Module is a synthesis of the statics and dynamics defining a C2 system.

MODULE 5: SPECIFICATION OF MEASURES

Based upon the four prior modules, the fifth module specifies the measures necessary to address the problem of interest. The definitional categories identified above may be employed to derive a complete set of relevant measures, which are then subjected to further scrutiny. First, as shown in Figure 5, these are compared to a set of desired characteristics for measures, which reduces the number to a more manageable set.

There is an alternative method to specifying measures. In this case, the matrix describing the C2 architecture is completed at the level of detail appropriate to the problem at hand. Accordingly, one to "n" entries can be made in each cell of the 3 by 4 matrix, shown in Figure 4. The first two rows, elements and subsystems, represent classes, whose effected members would be selected.

CHARACTERISTICS	DEFINITION
Mission Oriented	Relates to force/system mission.
Discriminatory	Identifies real differences between alternatives.
Measurable	Can be computed or estimated.
Quantitative	Can be assigned numbers or ranked.
Realistic	Relates realistically to the C2 system and associated uncertainties.
Objective	Can be defined or derived, independent of subjective opinion. (It is recognized that some measures cannot be objectively defined.)
Appropriate	Relates to acceptable standards and analysis objectives,
Sensitive	Reflects changes in system variables.
Inclusive	Reflects those standards required by the analysis objectives,
Independent	Is mutually exclusive with respect to other measures.
Simple	Is easily understood by the user.

FIGURE 5

DESIRED CHARACTERISTICS FOR EVALUATION MEASURES

One or more measures, suitable to both the problem at hand and the data generator available are identified. (In the event that both conditions cannot be satisfied, the nature of the problem must have the greater influence.) These measures are then taken as the critical or minimum essential set of measures for the problem at hand.

The appropriate approach may be selected by conducting an experiment with a small excursion within the same problem domain. Such a small study excursion would involve a problem for which the set of exhaustive measures is relatively small and easily instrumented. A test will determine the estimated percent of variance accounted for by the "selected set". If the decisionmaker finds this variance comfortable, the comparative cost of the selective vs. exhaustive technique could be determined. To these two factors, a third, speed of producing usable results should be added.

The final set of measures selected are classified as to their level of measurement, i.e., measures of performance (MOPs), measures of effectiveness (MOEs), or measures of force effectiveness (MOFEs). The names chosen also link to the kind of conclusion that can be drawn in an analysis to which the measures are applied.

The implementation of this Module results in the specification of a set of measures focussed primarily on the C2 process functions; however, it also often includes the static components of the C2 system.

MODULE 6: DATA GENERATION

The generation of values for the measures of Module 5 is addressed by this Module. Here, one of several types of data generators, (i.e., exercises, experiments, simulations, or subjective judgements, - aka relevant experiences) is selected. The measures or variables for measuring effectiveness are specified in the prior Module.

Using the designated data generator, the values to be associated with these measures are the resultant output of the implementation of this Module. These values may be either measured directly, or be derived from those measured directly.

MODULE 7: AGGREGATION OF MEASURES

The final Module addresses the issue of how to aggregate the observed values for the measures. The three levels of measurement, together with sets of variables through which values on each level are generated, are available.

Different problem areas, addressing different decision-makers analytic needs, will result in differing requirements for and justification of the algorithms for the aggregation of the constituent measures.

The implementation of this Module provides the analysis results tailored to address the problem initially posed by the decisionmaker and is further qualified in the Problem Formulation Module.

SUMMARY OF THE MCES

At least two courses of action are available to the decisionmaker, based on results provided. On the one hand, he may directly implement the results of the MCES-driven analysis, if they are framed to permit such action. Alternatively, he may identify the need for further study and change the problem statement, requiring iteration of the MCES analysis. It should be noted that during the course of either the first or subsequent iterations, the decisionmaker may interact with the MCES analysis effort by identifying errors in assumptions, clarifying the bounding, etc. Modifying the direction taken in the analysis would be accomplished by infusing new directions or objectives based upon the results of the Module completed.

For example, bounding the C2 system may generate the observation that significant interfaces are outside the scope of the study as originally conceived.

TEST OF THE MCES

The remainder of this report covers the detailed application of the MCES. Examples were taken from all services and from Joint operations. One example in particular is highlighted. It concerns an analysis of a Naval Battle Force Architecture. This is called "The Designated Architecture".

Several other examples were considered in less detail. These are called "The Selected Architectures".

The choice of case histories was partially motivated by historical consideration, as related to community participation in the forerunner Workshops on the general question of C2/C3 measures of effectiveness. Before beginning a detailed discussion of the principal case histories, some historical background is in order.

BACKGROUND

THE MEASURES OF EFFECTIVENESS PHASE

The 1984 a Symposium entitled "Measures of Effectiveness for C3 Evaluation Symposium" was held at MITRE Corporation, Bedford, MA. It was initially triggered by a challenge from General Eaglet in his role as Deputy Chief of Staff, Plans and Programs, Headquarters, Air Force Systems Command. Specifically, General Eaglet invited Air Force planners to determine the force effectiveness of C2 systems. A major implication was that the approach taken should provide a methodology that will allow "cradle to grave" analysis of C2 systems. This requirement is often expressed and rarely found among previously employed assessment structures.

The expert knowledge of the analytic community was focussed to respond to this issue, through the mechanism of the Symposium and its Working Groups. Under Symposium Chairmen, Dr. Ricki Sweet and LTC Thomas Fagan III, five working groups were formed.

The Working Group Chairmen were:

Dr. Zitta Z. Friedlander, The MITRE Corporation;
Griffin F. Hamilton, EASTAN Corporation;
Linda Hill, SAI;
Dennis Holstein, LOGICON; and
Richard Hu, Naval Sea Systems Command.

This was the beginning of a grass roots involvement by the analytic community in the subject of C2 Evaluation to which this report is heir. The topics addressed by the working groups included: working definitions, conceptual models, the identification of MOEs, evaluation techniques and approaches, and an overall appraisal of the current status and future course of MOE analysis.

Deliberations of the 1984 Symposium were reported to an audience of close to 100 attendees at the 52nd MORS C-3 (Measures of Effectiveness) Working Group. Presentations were made by the Working Group Chairmen as well as by LTC Edward C. Jonson, Director of Long Range Planning, ESD/XR; Ted Jarvis, The MITRE Corporation; and Dr. Morton L. Metersky, NADC.

Based on the expressed interest and need for further attention to the problem of evaluating C2 systems in terms of their contribution to force effectiveness, MORS sponsored an interim Workshop, based upon a proposal developed by Dr. Sweet, Dr. Michael G. Sovereign, Chairman, Joint C3 Academic Group, Naval Postgraduate School, and Dr. Metersky.

A C2 Measures of Effectiveness "Strawman" provided the participants with a framework for their subsequent deliberations. The Strawman was developed by the Workshop organizers, together with the 1985 working group chairmen, each of whom had a specific subject matter responsibility.

Dr. William Foster, The MITRE Corporation, headed the "Applications" working group. Mr. Walker Land, The IBM Corporation, chaired the "Conceptual Model" working group. Mr. Richard "Hap" Miller, OSD, guided the "MOE Specification" working group. Dr. Stuart Brodsky, The Sperry Corporation, spearheaded the "Mathematics Formulation" working group.

At the end of the 1985 C2 MOE Workshop, the Strawman had been critically reviewed and revised. Thereafter, the process of preparing an integrated presentation of this work proceeded.

A report was presented at a Special Session of the 53rd MORS. This report was in the form of seven presentations, one from each of the organizers and one from each of the working group chairmen. (Mr. Charles Smith of Nichols Research Corporation replaced Mr. Miller and Dr. Conrad Strack of Systems Planning Corporation replaced Dr. Brodsky for these presentations.)

The final draft of the Workshop deliberations was presented to the attendees, the MORS Board of Directors and participants from the Workshop. Comments received from these "reviewers" were integrated into the document. This document was published as a MORS sponsored document in June 1986.

THE MCES PHASE I: EMERGENCE

In the meantime, the organizers developed a follow-on proposal to further apply the structure which evolved from the prior meetings. Under MORS sponsorship, jointly with the Naval Postgraduate School, six working group chairmen were recruited to expand and apply the MCES methodology to specifically evaluate the effectiveness (or force effectiveness) of C2 systems.

Six service community input application candidates were suggested. Each was proposed by a sponsor and was represented at the Workshop by the "Problem Advocate".

The Army Tactical architectural candidate problem, brought by Maj. B. Galing and Maj. R. Wimberly of the TRADOC Research Element in Monterey, posed the question "How can the SHORAD/FAAD Platoon command and control be improved to increase the number of engagements of threat aircraft?

The Air Force Tactical architectural candidate problem, brought by Maj. P. Gandee on behalf of Col. D. Archino, test director of the Identification Friend, Foe, Neutral (IFFN) testbed (Kirtland AFB), centered upon the utilization of the IFFN testbed to evaluate the flow of C2 information throughout the C2 structure specific to air defense. The question addressed was "is this structure useful in evaluating information collected to determine who was winning the war?"

The Air Force Strategic architectural candidate problem, brought jointly by Maj. Bruce Thieman of OJCS-C3S and Dr. Tom Rona of OSD/DASD was to perform a mission analysis to define a concept definition for a strategic command and control (SCC) system in the circa 2000-2020 time frame.

The Navy Tactical architectural candidate problem, brought by Prof. Dennis Mensh, on behalf of the NSWC, was to develop architectures for battle force information systems.

The architectures were to relate measures of effectiveness of command and control of a Navy Anti-Air Warfare (AAW) System, the C2 Process model and Navy functional flow diagrams and description (F2D2) Process (presently used by COMSPAWAR)

The Joint Tactical architectural candidate problem, brought by Lt. Bruce Nagy, NOSC, centered upon the definition of measures to evaluate TADIL J communications protocol. This turned out to be two problems: (1) the comparison of implementation with protocol specifications, and (2) given implementation, the determination of how well the TADIL J system supports required information exchanges among joint tactical data systems (TDS).

The Joint Strategic architectural candidate problem, brought by Dr. M. Leonardo on behalf of SDIO, centered upon the development of a concept of operations for C2 of ICBM launch detection (LD) sensors.

During the 1986 Workshop on the Evaluation of C2 Systems, these application studies were scoped, i.e., a plan to carry out an appropriate analysis, guided by the MCES, was developed. All participants, especially the problem advocates, endorsed the methodology and the scoping of the problem which resulted from those deliberations.

The results of this Workshop were presented at a Special Session of MORS in June, 1986 by the chairmen of the Working Groups.

This effort represented the voluntary contributions by government, military, and civilian agencies, and by companies associated with DOD, as well as the personal contribution of time and energy of over one hundred experts. Coordination of such an effort has been the single most challenging aspect of this endeavor; all the individuals involved are overloaded by their own work plans, and respond to the deadlines and constraints of this work in the spare time that only very busy people seem to find.

THE MCES PHASE II: TEST

The detailed working out of a number of the 1986 Workshop candidates forms the basis of this phase. Community involvement remained high at the selected host agencies. To that was added the work of student teams from the Naval Postgraduate School. For the first time in its evolution, this work was under the full-time management and direction of a Principal Investigator.

SUMMARY

The MCES development started with widespread community discussion leading to the mandate to develop a generic approach to the evaluation of C2 systems. The objectives of this approach were to develop and, to the extent possible, to quantify measures of effectiveness appropriate to the C2 systems of interest.

Further, wherever relevant, it should be attempted to relate the C2 system to some measure(s) of its contribution to force effectiveness. Finally, all phases of the life cycle of the military system should be amenable to analysis using this approach. Indeed, a single system should be able to be continuously evaluated during its tenure.

The MCES evolved as any scientific development: (1) public discussion and mandate for clarification; (2) setting up the nature of the problem, the tools, definitions, and potential directions; (3) first order development of the identified components; (4) specification of the interrelationships of the components; (5) testing of the theory with real problems, i.e., extra-laboratory experiments; and (6) refining the structure in accordance with the test results.

Throughout this process, tools and models which provide depth in one or more of the Modules, are identified, developed, and/or integrated into the MCES. Today, having gone through the first cycle of this scientific development, the many participants in this journey look forward to the continuing iteration of the last two steps. This process, we are confident, will lead to a further refined, bounded and specified generic methodology that will fulfill many of the requirements implied by the initial direction.

THE OJCS-C3S SPONSORED WORK:
A C3 ARCHITECTURE STUDY USING MCES METHODOLOGY

OVERVIEW

As indicated earlier, the OJCS-C3S initiative's objective was to provide a simple yet powerful paradigm with which to evaluate alternative C2 architectures. The first step was the development of the MCES. The second step is test and implementation. This chapter focuses on step two.

The architectural studies scoped as part of the 1986 Workshop were the candidates for the work undertaken in the OJCS-C3S initiative.

(1) The Navy Battle Force Architectural study, a follow-on to the Workshop Navy Tactical Working Group deliberations, is the specific detailed study which is considered a demonstration of principle.

(2) The IFFN problem represents the Air Force Tactical Problem from the Workshop and is a rather detailed scoping, which is being carried forward by the Workshop sponsors.

(3) The Air Force Strategic problem, called the SuperCINC problem after the Workshop, was carried through the first two modules of the MCES in some detail.

(4) In addition, a new study related to the set of OSD-identified critical C3I problems from which the SuperCINC problem was taken, has been added. This is identified as the SAC operational testing problem and relates to the integration of new equipment into an existing architecture.

These four problems will be presented in varying detail in subsequent sections of this chapter.

(5) The SDI problem was undertaken as the Joint Strategic problem. The architectural issues were to examine the assignment of functions to people/platforms. However, the designated analytic need was found to be immature in its formulation to continue under this study. Indeed, we have learned that the MCES must often be employed more than once to scope a problem in concept development. Further, this experience has pointed out that in an arena where there are a large number of deferentially tasked actors, the MCES cannot be effectively used to impose order.

Instead, a second scoping, under separate funding, is being undertaken for a subset of SDI-related measurement problems, where the participants recognize the need for a synthesized approach to the problem.

(6) and (7) Finally, two of the Workshop problems were not further developed under this study. The Army SHORAD problem was set aside pending resources to continue further. The Joint Tactical Problem was to be separately continued under the aegis of the sponsors of the problem, NOSC.

THE DESIGNATED ARCHITECTURE:
NAVY BATTLE FORCE ARCHITECTURAL STUDY

This study was undertaken with the primary support of the Naval Surface Weapons Center (NSWC). Dr. Ricki Sweet was Principal Investigator. Prof. Dennis Mensh was the senior analyst and technical and scientific advisor in behalf of NSWC for this research. NSWC will use this research to provide appropriate measures reflecting the command and control process into data generation tools, such as the Ship Combat Simulation System (SCSS). This study is *unclassified.*

In this study, a complete iteration of the MCES is conducted. The results of each Module are summarized. A separate study contains another detailed application of the MCES. The latter should be regarded as a detailed case history for architectural design environments. It should be considered as a source document for someone wishing to experiment with the MCES at this time. Together with the work of Maj. Pat Gandee, the two comprise the most detailed evaluations using the MCES. These documents are presented in the Appendix to this report.

MODULE 1: PROBLEM FORMULATION

The Initial Problem Statement:

The objective of this research was to demonstrate the utility of the MCES in the evaluation of competing C2 architectures by focussing upon both system and procedural changes. The subject of this research is Navy Battle Force Architectural analyses.

Assumptions:

Architectural analyses require first the determination of what the system is to do; next, how it is to do it; and finally, how we will know it is done. Functionality is seen as the given. Alternatives are seen as different architectures and/or different operating modes. The measures defined are the parameters within which evaluation of competing architectures is accomplished.

Accordingly, the MCES may be designated as the structured guide through the inherent analysis process. The route will be illustrated through the data generated by a Navy Battle Force exercise, The Level Of Decision:

What life cycle phase is the program in?

In general, the SCSS is used in the design phases of combat systems. The NSWC-sponsored research was a feasibility study which focussed upon inputting operational environment data to this design tool. New databases to be imbedded in the SCSS can be based upon the data from a real world exercise so that these databases will explicitly reflect previously implicit command and control operations.

At what management level is the decision maker?

The decision maker in this case is at the division level. It is expected that NSWC will staff the results of the study and make recommendations to SPAWAR Working Group III under Capt. Hay. This effort will be focussed upon the improvement of modeling and simulation efforts in behalf of evaluation of competing C2 systems by inserting exercise data as validation/verification of the databases used by the existing models and simulations.

Critical Elements To Describe The System Of Interest

The following question was formulated for the problem addressed by this study:

> What is the concept of operations for the exercise in which the Navy Battle Force Architecture is expected to operate?

> The exercise's operational concept is classified. It is provided in Readiex 86-1 Script/Operational concept. For the purposes of this analysis, the composite warfare coordinator (CWC) concept is employed, thus a delegated pattern of authority is the focal point of the training and demonstration of the exercise.

MODULES 2 AND 3: C2 SYSTEM BOUNDING AND C2 PROCESS DEFINITION

MCES provides definitional guidance for the bounding and process definition Modules. A matrix whose columns represent the components of a system, i.e., physical entities, structure, and process, (ref. 1).

Process refers to functionality or what the system is doing, i.e., plan, sense, assess, generate, select, and direct. In this problem, plan is taken as a pre-real time activity, and is considered the first command and control process function.

The rows of this definitional matrix are denoted by a hierarchical view of systems, i.e., elements, subsystems, system and architecture. The "element" is the lowest level; "architecture" is the top level.

Figure 6 provides an example of the results of the System Bounding and Process Definition. This leads to development of measures for quantifying the dimensionality of the system, the performance of the system, and the effectiveness of a combat system in terms of the overall system performance.

MODULE 4: INTEGRATION OF STATICS AND DYNAMICS

Statics and dynamics address the various architectures that are being analyzed. Statics is equivalent to the physical entities and the structure. Since the structure changes very slowly over time, it can be taken as quasi-static; whereas "dynamics" is equivalent to the process, which changes rapidly. At the element level, the "sensor" performs the sense function.

	STATICS		DYNAMICS
	PHYSICAL ENTITIES	STRUCTURE	PROCESS
ELEMENTS	SENSOR	SENSOR OPERATOR POSITION	SENSE
SUBSYSTEM	COMBAT SYSTEM	ALPHA WHISKEY	ASSESS/GEN-ERATE/PLAN
SYSTEM	TACTICAL FLAG COMMAND CENTER (TFCC)	COMPOSITE WAR - FARE COORDINATOR (CWC)	ASSESS/PLAN SELECT/GEN-ERATE/PLAN DIRECT
ARCHITECTURE	BATTLE FORCE	BATTLE FORCE INFORMATION MGMNT (BFIM)	ASSESS/PLAN SELECT/GENE RATE/DIRECT

FIGURE 6

NAVY BATTLE FORCE EXAMPLE OF SYSTEM BOUNDING AND PROCESS DEFINITION

At the subsystem (relative to the battle-force) level, the combat system, composed of physical entities, as defined above, is employed by an organizational unit, a Warfare Area, e.g., Alpha Whiskey, and performs the functions "plan", "assess", "generate", "select", and "direct".

For the purposes of this analysis, the integration is accomplished by making explicit the relationships among these components.

As shown at the element level in the Figure 6 example, the sensor, a piece of equipment, is assigned to the Sensor Operator Next, at the system level, Tactical Flag Command Center (TFCC), also composed of the same physical entities as at the subsytem level, performs similar functions at a higher level. Finally, at the architecture level, the battle force, similarly composed, is organizationally responsible as the battle force information management system, which performs its functions at the highest level.

There is a similar relationship between the entries of the columns. For physical entities, the sensor provides information from the environment upon which a target assessment is made by the combat system. The combat system transmits the assessment to the TFCC, which is used by the battle force.

The organizational structure is directly hierarchical. Finally, the process can be seen as distributed between the levels indicated. The relationship between the column entries is also important in relation to aggregation of measures.

After these relationships are made explicit, the MCES provides the guidance for a set of both quantitative and qualitative measures based upon any selected form of data generation. These are geared to the application objectives of the decisionmaker. All data generation techniques should output values for a standard set of measures to be used to evaluate competing architectural alternatives. Specification of measures, data generation, aggregation of measures and the presentation of data to the decisionmaker are subsequently discussed.

MODULE 5: SPECIFICATION OF MEASURES

The MCES provides a framework for specification of measures. Four types of measures are given. Two are measured inside the boundary of the C2 system, i.e., dimensional parameters and MOPs. Two are measured outside the boundary of the C2 system, i.e., MOEs and MOFEs.

The boundary is taken to be the delineation between the system being studied and its environment, e.g., if the physical entities of the system of interest are located in the command post (TFCC), its external elements include aircraft, ships and their associated combat systems; its internal elements include subsystems such as sensors, computers, and internal communication. (It may be necessary to reflect such environmental entities as scenarios and threats for some specific measures.) It should be clear that the boundary varies with the analysis being undertaken. However, for any set of alternatives being evaluated the boundary is fixed across systems.

"Dimensional parameters" are defined as the properties or characteristics inherent in the physical entities whose values determine system behavior and the structure under question, even when at rest (size, weight, aperture size, capacity, number of pixels, luminosity).

"MOPs" are also closely related to inherent parameters (physical and structural) but measure attributes of system behavior such as "gain", "throughput", "error rate", "false alarm rate", and "signal-to-noise ratio". In short, MOPs reflect the "what" of the system. Figure 7 presents an example of the matrix of MOPs that correspond to the statics and dynamics of Figure 6.

	STATICS		DYNAMICS
	PHYSICAL ENTITIES	STRUCTURE	PROCESS
ELEMENTS	"FALSE ALARM RATE"	"SUSCEPTIBILITY TO FALSE TRACKS"	"NO. OF OBJ ID'D"
SUBSYSTEM	"NO. OF COMMUNICATION CHANNELS"	"NO. OF MSGS. INITIATED, RECEIVED, OR MONITORED"	"TEMPO"
SYSTEM	"NO. OF ENGAGEMENT ORDERS"	"NO. OF TASKS PERFORMED OVER WHICH DIRECT CONTROL IS EXERCISED"	"FREQUENCY OF PROCESS FUNCTIONS"
ARCHITECTURE	"FUNCTIONAL INTEROPERABILITY"	"NO. OF TASKS PERFORMED WHICH ARE SPECIFIED UNDER CONCEPT OF OPERATIONS USED	"NO. OF CONTINGENCIES PROMULGATED"

FIGURE 7

NAVY BATTLE FORCE EXAMPLE OF MOP MATRIX

"MOEs" measures how well the C2 system performs its functions in an operational environment. Implicit or explicit reference to a standard against which "effectiveness" can be ascertained is required. The standard may reflect predicted perfect performance, e.g., probability of detection implies the potential of all objects in the environment being detected. Some examples are "probability of detection", "reaction time", "number of targets nominated for engagement", and "susceptibility of deception".

"MOFEs" are a measure of how a C2 system and the force (sensors, C2 system, and weapons) of which it is a part performs missions. An example might be "surviving and connected warheads". At this time, MOFEs derived from the exercise data are not available.

MODULE 6: DATA GENERATION

A number of methods may be used to generate data for MOPs, MOEs, and MOFEs. Existing simulation programs and models are both general and detailed.

This report uses the guidance provided above to extract some of the appropriate data required by Figures 6 & 7 from an at-sea exercise. The tasks involved in this effort include:

1. Identification of appropriate measures:

Based upon the guidance provided by the MCES, the following MOPs were identified as appropriate to the evaluation of the mission performance evidenced in an exercise: tempo; organization; (C2 Process) function; time; tempo by organization; tempo by (C2 Process) function; structure by (C2 Process) function; function by organization by time; and bias measures, e.g., missing functions.

2. Definition of selected measures:

a. Tempo. Tempo represents the frequency and number of activities over the duration of the exercise. Operationally, this measure depends upon the accuracy of the log keeper. Each entry in the log is entered on a time line identified by day and indexed in accordance with military time. The pattern of these "hash marks" is taken to represent the tempo of operations during the exercise. Since a time line is essential to designate tempo, this measure is inclusive of the time measure. Figure 8 shows the tempo of operations during an approximately six hour slice of day 1 of the exercise.

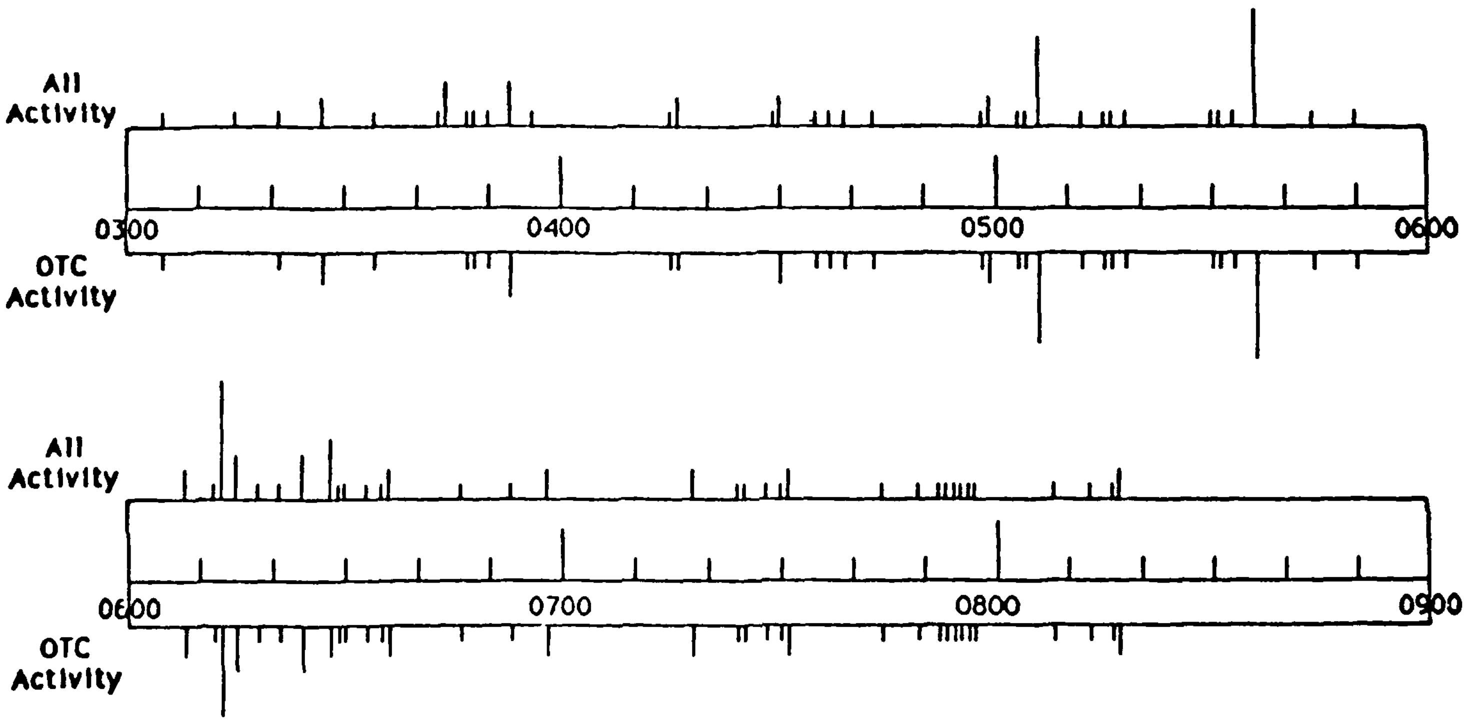


FIGURE 8

NAVY BATTLE FORCE MOPS: TEMPO OF OPERATIONS

b. Organization. Four organizations are represented in the exercise studied herein. These may be described in terms of the mission area they represent within the overall CWC (Composite Warfare Coordinator) structure. The four organizations are ASW (Anti-Submarine Warfare), ASUW (Anti-Surface Warfare), AAW (Anti-Air Warfare) and EW (Electronic Warfare). Activities relating to each organization are reported for that organization separately. The logs indicate data from the perspective of the OTC and the ASUWC. The organization is both the subject and the object of the log entries shown. Two or more organizational entities may be represented by the same entry. Figure 9 indicates organizational structure in terms of direction of information flow, i.e., messages received by or initiated by the OTC.

c. (C2 Process) functions. These functions are defined in ref. (1) Section 5.4.1.1. Operationally, the logs do not always allow a one-to-one mapping of entries to functions. Therefore, if log entries were not explicit, operational experience was used to map the entries to the functions. Often, the nature of the logs prevented single function determination.

FUNCTION PERFORMED	MESSAGES LOGGED
MONITOR	45
INITIATE	35
RECEIVE	27

FIGURE 9

NAVY BATTLE FORCE MOPS: ORGANIZATIONAL STRUCTURE

In those cases, the largest set of functions that would accommodate all the implied functions was used for such occurrences. It is clear that for the exercise log, there is no single-thread extractable independent set of measures.

Each of these subsets may be seen separately but since some are not independent, the explanation and assigned value for the set is complex. At one extreme, those sets may be seen as arbitrarily grouped, due to the interpretation of the log. Alternatively, a "set" may represent a unique internal feedback relationship. Of course, there are many other potential explanations. The implications for measurement vary, based upon the explanation adopted. Figure 10 shows the C2 Process functions and their frequencies during the same period of time during the exercise.

d. Time. Time, as opposed to tempo, relates only to the elapsed time (by day). Time can be segmented by looking at the elapsed time between events or a single time designation (representing the elapsed time from an arbitrary origin, i.e., midnight) may be used.

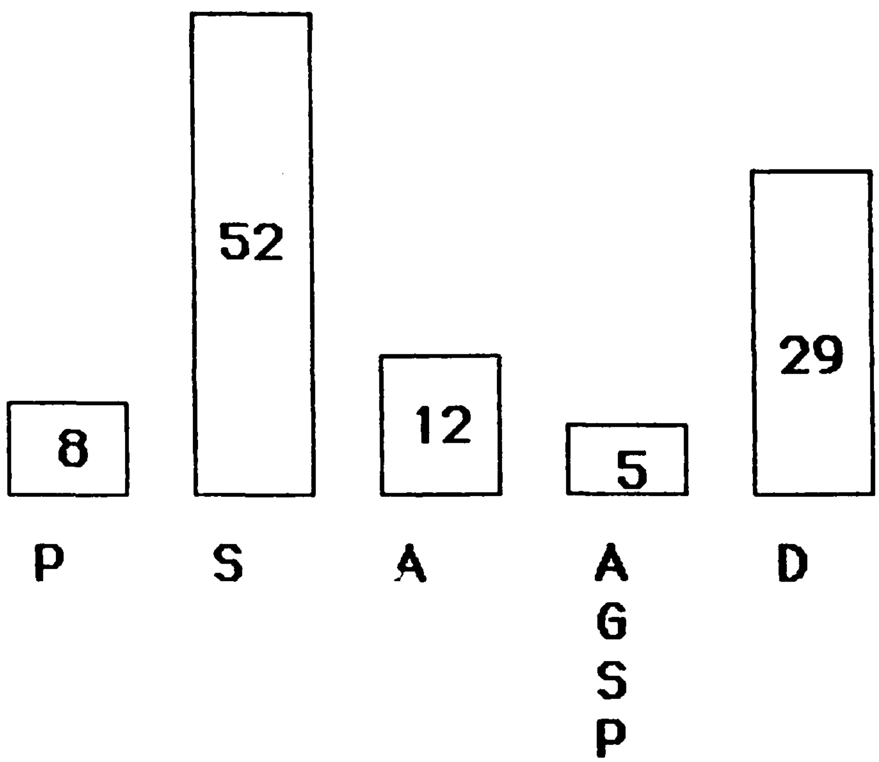


FIGURE 10

NAVY BATTLE FORCE MOPS: C2 PROCESS FUNCTIONS

Since "time" meets all the measurement criteria for a ratio scale, it is particularly convenient to use a time scale upon which to relate all other measures. Time is shown in Figure 8.

e. Interactions.

(1) Two-way interactions reflect the relationships between the columns in Figure 6. These include:

(a) Organizational stress. Here the tempo of activities, subject to the limitations of reporting, indicated above, are reported separately for each warfare area. Tempo for all exercise activities and for activities at the OTC is also shown in Figure 8.

(b) Functional information flow. Subject to the limitation of independence discussed above, functions are designated by the information flow patterns. Figure 11 indicates the extent and direction of such occurrences.

S	39		13
A	2	2	8
AGSP		3	2
P		5	3
D	3	25	1
	MONITOR	INITIATE	RECEIVE

FIGURE 11

NAVY BATTLE FORCE MOPS: FUNCTIONAL INFORMATION FLOW

(c) Functional stress. Each function set may be designated on a separate time line and a separate hash mark indicated at each time where the set may be inferred to have occurred, based upon log entries. Figures 8 and 12 show this relationship for the OTC.

(2) Functional Interoperability - The three-way interaction of variables, function by organization by time, may be shown by linking the same functional sub-set across time lines. This linkage may be inferred from Figure 12. Such a process assumes there is a natural causal and temporal relationship or sequence in the occurrence of the set from one organization to another, e.g., the AGSP sub-set occurs at the ASUW organization at 0715 thereafter at AAW at 0820. These two occurrences are assumed to be causally and temporally linked and are therefore graphically joined. Alternatively, a sequence, or scale, from one sub-set to another may be assumed, e.g., (1) sense (S), (2) sense/assess (SA)...(10) Direct (D). Figure 10 shows the points on the scale which would evolve.

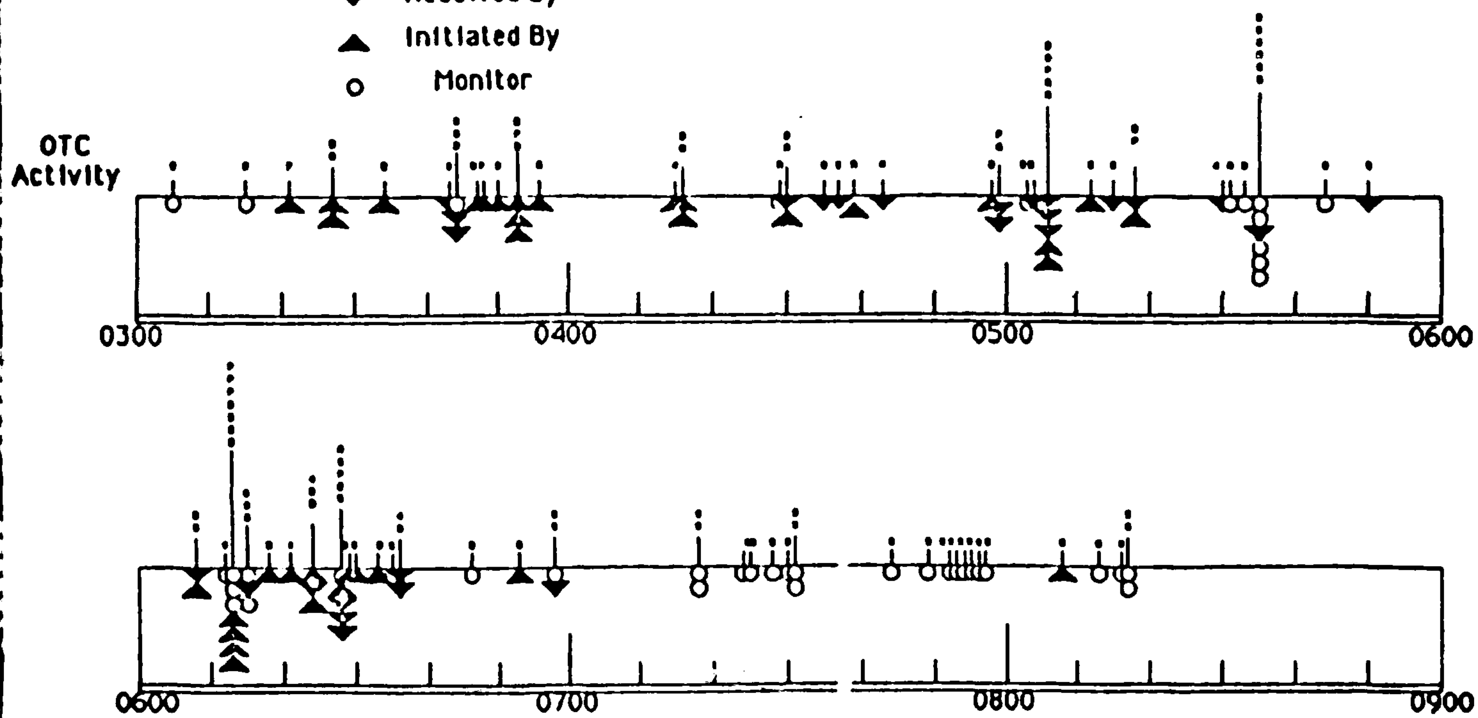


FIGURE 12

NAVY BATTLE FORCE MOPS: FUNCTIONAL STRESS

If one accepts the sequence and causality assumptions, points could be linked according to assigned ordinal scale values across time lines for each organization.

This interaction may also be taken as the formal definition of "functional interoperability".

(a) Bias measures

In addition to the sources of bias indicated above, four specific indications of bias in the underlying data, i.e., the logs, must be noted.

1. Missing functions. If we assume an essential sequence to the functions, even defined as broadly as indicated above, there is evidence of functions missing from the logs from which to infer the appropriate functional sub-set.

2. Errors in functions. These mis-IDed, are considered as valid data for the C2 process functions. Within the exercise, as reported in the log, there were functions which were incorrectly performed.

3. Missing data. There are long periods of no data from the logs, the activity during which we have no way of inferring; and

4. Observer unreliability. There are clearly differences in recording style and content between different keepers of the exercise logs.

In the attempt to provide appropriate measures to address evaluation issues, all of the measures discussed, except those relevant to time, are MOPs. Time-based measures and those which are compared with the exercise script (representing ground truth) are MOEs. In the sense intended here, "ground truth" is taken as the set of standards which system parameters must meet in order to determine the level of effectiveness to be determined.

Ultimately, a few measures can be developed from the exercise data for MOFEs. Since one mission objective of the scenario script for the exercise was to get through the choke point, an MOFE could be derived which reflects the extent of this mission accomplishment. As an example of such a MOFE, the number of ships that went through the choke point could be compared with the number of ships which were supposed to go through the choke point.

MODULE 7: AGGREGATION OF MEASURES

A number of measures describe each entry in columns of Figure 6. However, the meaningfulness of this process may be questioned when applied across entries, even though it is mathematically possible to aggregate measures. Some of these, of course, will be directly aggregable, e.g., time for the sensor to detect a contact may be added to the time for the combat system to assess the contact as hostile, friendly or neutral, which may be added to other time intervals to get an overall reaction time. Some will be indirectly aggregated since they are essential to the calculation of the measures propelled forward, e.g., sensor probability of detection is a function of the false alarm rate, rate not meaningful as an independent measure at the combat system level.

Finally, there are qualitative measures necessary for evaluation at each level, but not able to be manipulated within our usual analytic techniques. This latter group falls within "research to be done" and "techniques about which the community is yet to be educated (or convinced)" from the standpoint of adoption.

FEEDBACK TO THE DECISION-MAKER

The results derived in this study were briefed to the sponsor, NSWC, on 22 July 1986. Findings developed in this Battle Force Architectural Study and in the overall OJCS-C3S study were briefed at several separate meeting of the Warfare Systems Architecture Working Group II meetings from June through August 1986. This cross fertilization has been particularly helpful to this study in that it forced clarification of both the concepts and their communication.

SUMMARY

The findings of this application were accepted by NSWC management and will be input to future work on this C2 architecture.

This research led to the following lessons learned in regard to the MCES as a tool for evaluating the effectiveness of command and control systems:

(1) MCES can be used to determine the necessary data to be collected, estimated, or simulated for a data base so that the entries can be used to answer the C2 design problems at hand.

(2) MCES can be effectively applied to a combat system with strong C2 elements.

(3) MCES can be used to structure the collection of data in exercises.

(4) MCES was used to provide an operational definition of functional interoperability for the case at hand.

(5) This application lead to a series of in sights and expansions of the MCES:

a). The recognition that the relationships between the functions of the C2 process model are not linear, but are recursive, complex and undefinable at this time.

b). The plan function of the C2 process model may be considered in real or pre-real time. In the former case, it follows the Workshop generic model. In the latter case, it may be removed from the sequence or placed first in that sequence.

c) The matrix approach as an alternative to the onion skin forces an aggregational definition of architectures. Namely, elements aggregate to sub-systems to systems and finally to architectures.

d) The matrix approach to C2 analysis requires all three definitional components, in whole or in illustrative parts, to provide holistic data upon which to base evaluative conclusions re alternative architectures.

(6) MCES leads to the direct specification of a minimum essential set of measures for evaluation of C2 systems.

(7) MCES provided the concept for measures based upon real world inputs to study both interoperability and the inherent operational (and therefore acquisition) problems of both architectures and requirements.

THE SELECTED ARCHITECTURES: IFFN TESTBED ARCHITECTURAL STUDY

OVERVIEW

This study was undertaken with primary support of the Naval Postgraduate School and OJCS. Maj. Pat Gandee was the Investigator. As the thesis advisor, Dr. Ricki Sweet provided methodological guidance. Maj. Mike Gray and Col. Dave Archino provided technical and scientific advise on behalf of the IFFN testbed. The IFFN testbed will use this research to provide focus in test series number 2, currently in the detailed planning stage. The results reported here are unclassified. The IFFN problem represents the Air Force Tactical Problem from the 1985 Workshop. It is a rather detailed scoping of the problem and served as Maj Gandee's thesis primarily to support needs identified by the sponsors of the problem.

MODULE 1: PROBLEM FORMULATION

The goal of this study was to apply the MCES as an evaluation tool to examine the air defense C2 problem. The IFFN testbed addresses the air defense identification problem, a subset of the overall C2 problem.

The Initial Problem Statement:

The initial problem statement as developed during the 1985 Workshop, was:

> How effective is the air defense C2 system in the central region of Europe in providing decision-makers the means to assess and employ air defense assets to meet overall mission objectives? Different operational concerns were also to be considered, e.g., procedural control, so that questions such as "Under what conditions is centralized or decentralized control more effective?" could be answered.

Assumptions:

1. The mission and its environment (friends, foe, neutral, weather) are specified.

2. The friendly weapon systems are limited to SAMs and fighters with beyond visual range (BVR) munitions.

Scenario:

A conventional threat scenario was chosen where stress of the C2 system could be affected by varying traffic volume, ECM jamming of radars, communications jamming and varying weather conditions.

Level Of Decision:

What life cycle phase is the program in?

The operational test community is expected to use the results of this study to structure test designs to answer operational issues. The test concept uses men in the loop at command centers and in the weapon systems employing real world operational procedures against varied threat scenarios. The testbed is representative of the European air defense C2 system, and must operate in an environment of friendly, enemy and neutral aircraft to perform the air defense mission.

At what management level is the decisionmaker?

The IFFN testbed focuses its analysis on specific concerns of Army, Air Force, NATO and DOD decision-makers regarding the role of identification as it contributes to the effectiveness of the C2 process.

Critical Elements To Describe The System Of Interest:

Emphasizing the battle management functions necessary to control air defense forces in central Europe, the C2 system may be defined by:

1. Geographic areas of responsibility - for the IFFN testbed within the NATO 4ATAF sector, and

2. Physical elements needed to perform or support the C2 process - command centers and information sources.

The following question was formulated for the problem of the IFFN testbed:

How will the programmed C2 system and weapon systems operate together?

MODULE 2: C2 SYSTEM BOUNDING

The first component, physical entities, of the air defense system may be indicated by the command centers that perform the battle management functions. These are:

1. Sector Operations Center (SOC)
2. Control and Reporting Center (CRC)
3. Control and Reporting Post (CRP)
4. Brigade Fire Detection Center (BDG)
5. Battalion Fire Detection Center (BN)

Identification sources considered to be within the C2 system are:

1. NATO Airborne Early Warning System (NAEW)
2. Special information system (Intelligence) (SIS)
3. Other information Sources, e.g., flight plans.

Since weapon systems also perform command and control functions under certain operational concepts, the C2 system included the weapons systems when they performed C2 functions. The air defense weapon systems, are the F-15 Eagle (all weather fighter) and the HAWK and PATRIOT SAMs.

The second component of the C2 system bounding Module is structure. For this system, structure may be designated by information flow. The functional input/output describes the information flow between separate organizational entities and their respective C2 processes, which are required to perform the mission at hand.

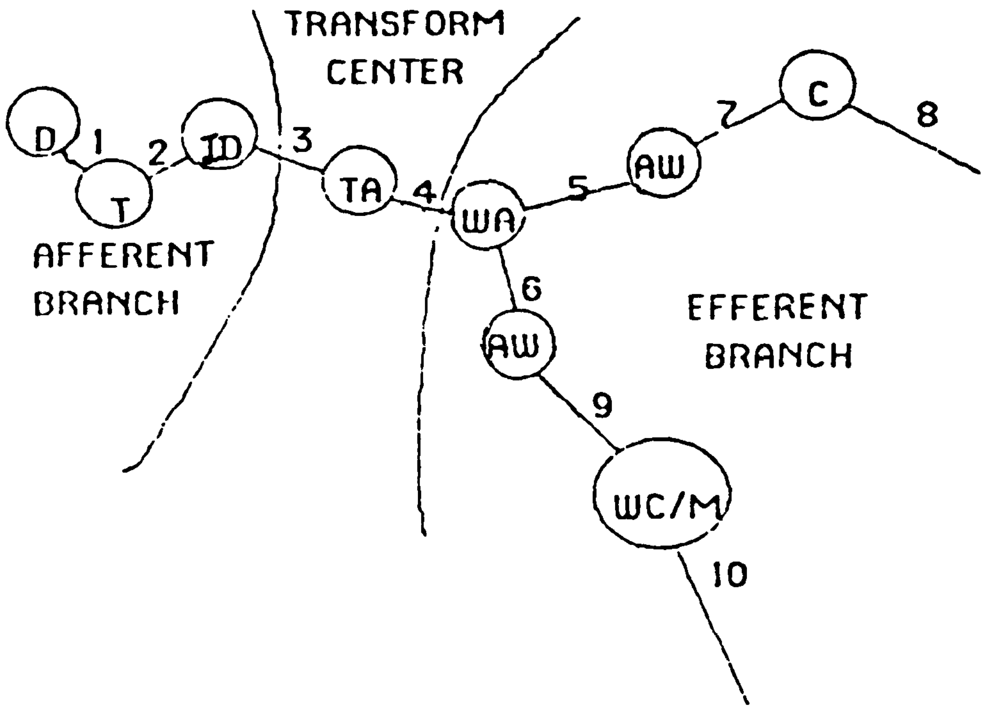
In this information flow, the commander and the subordinates perform separate C2 processes. These processes are related.

The commander's decision begins with information about a change in state in the environment (input) and ends with directions to his subordinates. These directions require the subordinates to perform some set of actions the commander has determined will remedy this change in state (output).

These orders are received by the subordinates as input to their process. The outputs from the subordinates' process are detailed instructions. These, in turn, are input to the force, thereby coupling this latter organizational entity to the prior two levels. Data flow diagrams (DFD), see Figure 13, describe the input/output relationships that exist between C2 functions (circle on the diagram). With this flow of information, a transform analysis may be shaped.

The first information set shown in this figure refers to target information. First, targets are DETECTED, then IDENTIFIED, and finally they are ASSESSED in relation to mission goals. The information flows from DETECT to IDENTIFY to ASSESS THREAT.

The second information set assigns enemy targets to SAMs or fighters and matches individual weapon systems to the targets.



1 RADAR CONTACT
2 CONTACT/POSITION/DIRECTION
3 FRIEND/FOE/NEUTRAL
4 PRIORITIZE FOE TARGETS
5 ASSIGN TARGET TO FIGHTERS
6 ASSIGN TARGET TO SAMS
7 ALLOCATE TARGET TO FIGHTER AND CONTROLLER
8 PROVIDE DIRECTION AND INFORMATION TO FIGHTER
9 ALLOCATE TARGET TO SAM FIRE UNIT
10 MONITOR ENGAGEMENTS

FIGURE 13

IFFN TESTBED STUDY: SINGLE C2 NODE DFD

ASSESS THREAT is the function where the main perception is formed. Information flows in to formulate perceptions. Information flows out as decisions based upon these perceptions.

Therefore, this function may be seen as the superordinate function. As such, it is called the C2 process center. A graphic of this transform analysis is shown in Figure 14.

MODULE 3: C2 PROCESS DEFINITION

IFFN JTF was dealing with a distributed C2 system. Therefore, the C2 system could not be viewed as a single C2 process. On the one hand, many lateral and vertical command centers were performing the same C2 process to direct weapons under their individual control. On the other hand, processes that provide support to the C2 system may be included. These processes are:

1. Intelligence (INTEL) to assign meaning to observed activities and situations and forecasts changes in the current situation.

2. Crosstell (XTEL), a subset of the communications process to provide for sharing of information throughout the C2 system to support decisions and their implementation.

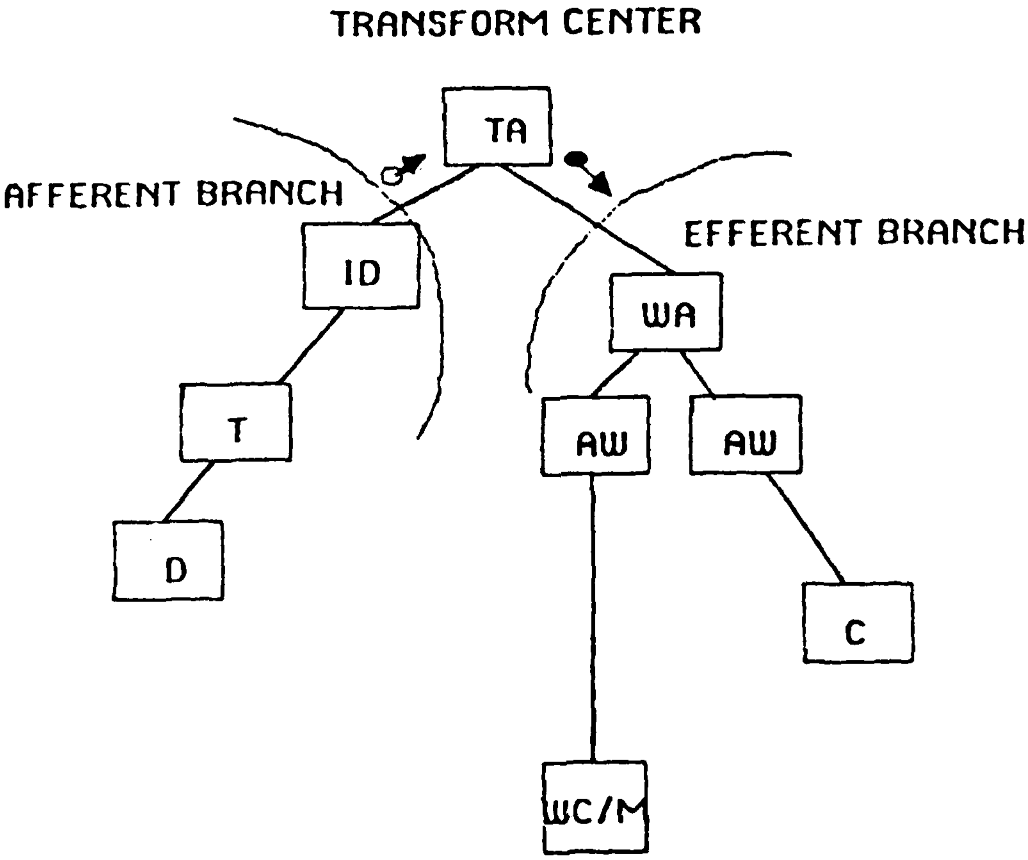


FIGURE 14

IFFN TESTBED STUDY: TRANSFORM ANALYSIS OF SINGLE C2 NODE

3. A separate "force process" is performed by the weapon system and its munitions. The functions of the force process are MANEUVER, ACQUIRE, ENGAGE and MISSILE FLYOUT.

Figure 15 shows the mapping of the Generic C2 process functions to the air defense functions. It should be noted that the planning function is performed in pre-real time, and as such, is at a different level from this execution level air defense process model loop.

In summary, XTEL and INTEL processes interfaced with the C2 process are ultimately linked to weapon systems which perform the mission. These processes stand alone as a dynamic description, apart from any particular command node, of what the C2 system is doing.

It should be noted that each command node potentially performs all C2 functions to direct actions in the environment. However, frequently operational concepts which distribute functions between command nodes (e.g., BFDCs and BNFDCs) or between command nodes and weapon systems (e.g., CRC and fighter) are employed. When this is the case, the analysis relating to the C2 process and the other related processes must take the nodal distribution of functions into account. The requirement for the air defense system is described in further detail in Module 4.

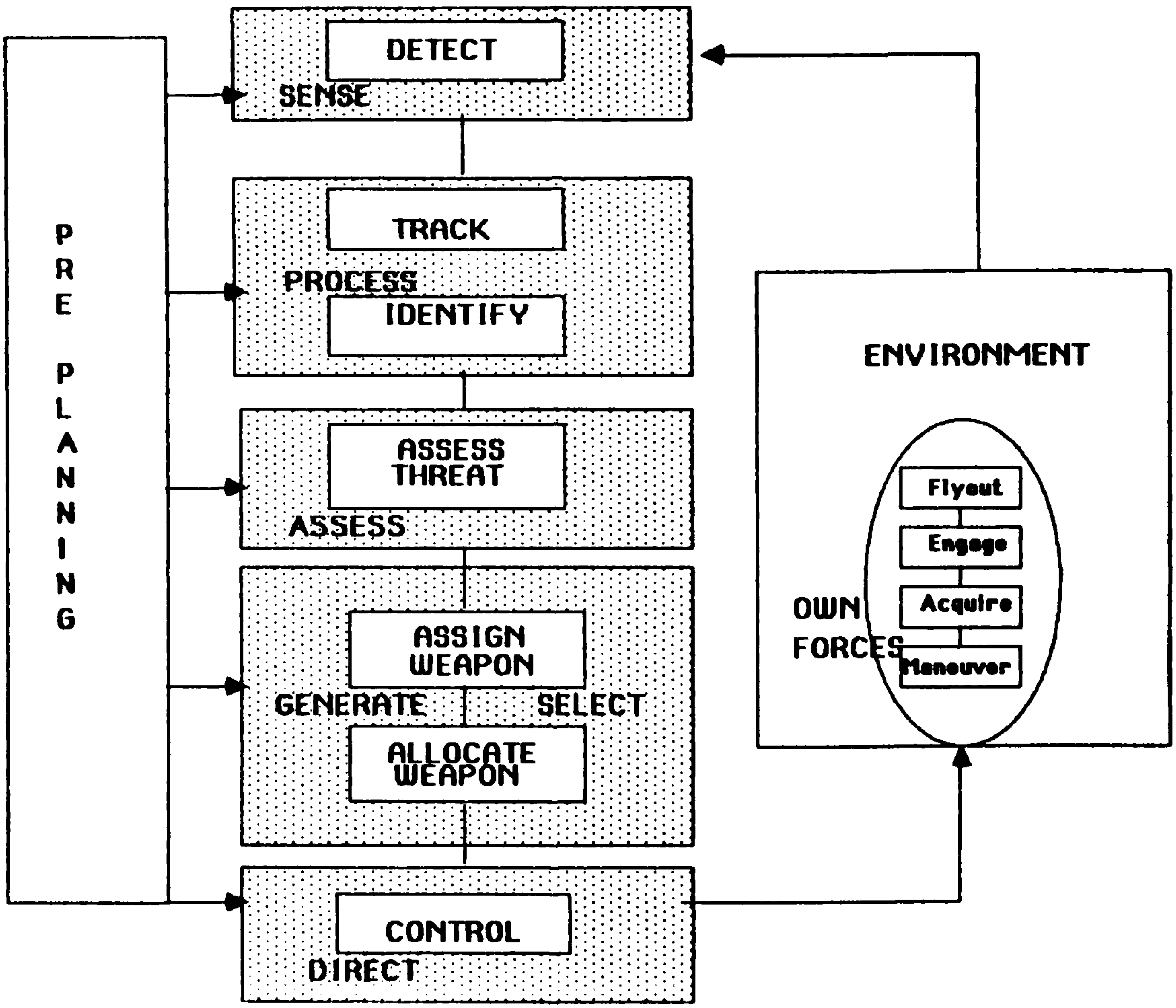


FIGURE 15

IFFN TESTBED STUDY:

MAPPING OF GENERIC C2 TO AIR DEFENSE PROCESS FUNCTIONS

MODULE 4: INTEGRATION OF STATICS AND DYNAMICS

When the physical entities in the form of the command center, (first component of Module 2), person and/or the machine which performs the function, (as specified in Module 3) are added to the information flow, (second component, of Module 2), the three dimensions of a C2 system: physical entities, structure and process, are integrated.

The people and their equipment can be matched to the structure. For example, a battle commander performs the ASSESS THREAT function. He is supported by the identification officer, whose subordinates are assignment officers. These latter officers implement the identification officer's decision as to which targets are most important to attack.

The equipment consoles may be viewed as capabilities which are implemented by reconfiguring consoles to assign targets or control weapons. Using DFD to describe the output of this matching provides a graphic depiction of the integration Module.

The DFD concept of a null process graphically describes the C2 functions specifically when they are distributed among nodes. These functions can not be duplicated, although they can be divided, e.g., BFDC allocates BNFDC and BNFDC allocates weapons system.

The null process indicates that only one execution level C2 process can direct a specified weapon system, although its decisions may be influenced by information coming from other similar processes, e.g., indirect ID or priorities from a higher echelon Figure 16 shows a representation of the null process by DFDs.

MODULE 5: SPECIFICATION OF MEASURES

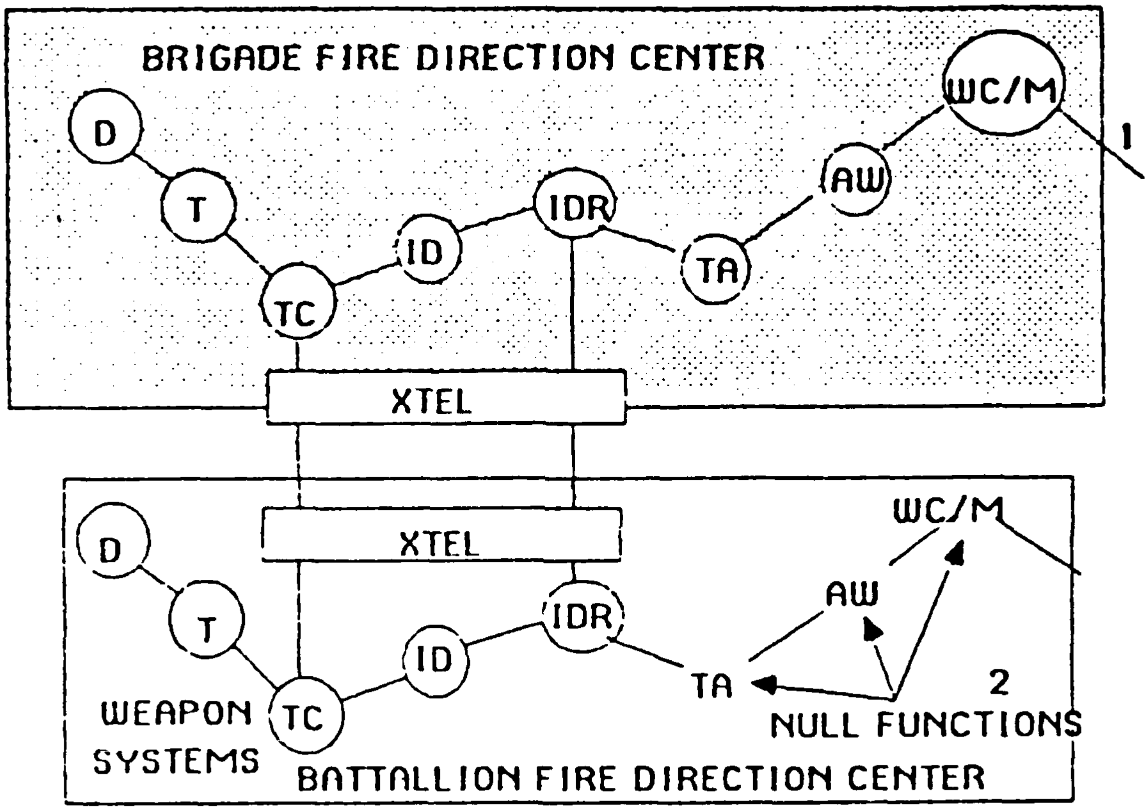
The measurement strategy couples the C2 process to the force process which accomplishes the mission. Since the IFFN processes reflect a distributed C2 system, measures which show the interaction between C2 processes must be used. Finally, these interactive measures must be related to overall mission measures.

MODULE 6: DATA GENERATION

It is expected that the IFFN testbed itself will be the data generator in subsequent iterations of this research.

MODULE 7: AGGREGATION OF MEASURES

This Module was not considered in this analysis.



1 CONTROL TO SAM A

2 THESE ARE NULL FUNCTIONS WITH RESPECT TO SAM A

FIGURE 16

IFFN TESTBED STUDY: NULL PROCESS WITH VERTICAL C2 NODES

FEEDBACK TO THE DECISION-MAKER

IFFN JTF staff and the IFFN Testbed Director, Col. Dave Archino, participated in the Workshop. He and Maj. Mike Gray of the IFFN JTF had previously provided direction to Maj. Pat Gandee in his preliminary search for a thesis topic. They also provided access to the Testbed library and other documentation to Maj. Gandee.

During the Pre-Workshop preparation, both Maj. Gandee and Dr. Sweet briefed the Testbed staff on the planned research. When Maj. Gandee's thesis was completed, he, Dr. Sweet, and Dr. Joel Lawson, a major participant in the Air Force Tactical Working Group, briefed the Testbed staff on the results of the research.

Finally, Dr. Alexander Levis of MIT and Earl Hicks of AF/SA joined Maj. Gandee, Dr. Sweet, Cpt. Larry Moss, USA and NPS student, Col. Archino, and Maj. Gray to discuss an article for Signal magazine reporting the impact of the MCES on the IFFN testbed. In all of these meetings, a standard mode of communication of findings to the decision-makers, as well as the impact of the IFFN testbed on mission effectiveness and its measurement, using MCES-guided analytic techniques, were the themes.

It is the belief of all concerned that Test Series 2 will show the ultimate benefit of these interactions. Data Generation, following the work done in the various reported efforts, will take place in Test Series 2. Aggregation and subsequent reporting will be taken up by the IFFN JTF staff. The recently completed Test Series 1 was planned without the insights provided by the MCES, the Workshop scoping, or the Gandee thesis work. However, these deliberations were input to the planning of Test Series 2 as well as to the interpretation of the first series test data.

Cpt. Larry Moss will continue to interact with the IFFN Testbed staff in the attempt to assess and expand the potential benefits of the MCES into the performance of the assigned tasks.

SUMMARY

The findings of this application were accepted by IFFN JTF management and will be input to future work on this C2 architecture.

This research led to the following lessons learned in regard to the MCES as a tool for evaluating the effectiveness of command and control systems:

(1) MCES can be used to determine the necessary data to be collected in a test series for an operational testbed to answer the C2 design problems at hand.

(2) MCES can be effectively applied to a combat system with strong C2 elements.

(3) MCES can be used to test alternative operational concepts.

(4) MCES provides insight into delegated and distributed organizational functions.

(5) This application lead to a series of in sights and expansions of the MCES:

a). The recognition that distributed functions require a hierarchical view of the C2 process model.

b). The indication that the C2 process Module may be applied uniquely in any given problem, depending upon the specific requirements of the problem.

c). An execution level process is defined as that which occurs when the C2 process is linked directly to the weapon system.

d). When an execution level C2 process is required in the problem, the plan function of the C2 process model should be considered in pre-real time.

e). In a mission level analysis, the C2 Process must be related to other processes, namely:

XTEL for sharing information;

INTEL for assessment of capabilities; and

FORCE for the weapon system and its munitions.

f). The C2 Process functions as given in any problem may be mapped to the generic C2 Process.

g). The MCES accommodates and demands an imbedded set of alternative tools. For organizational structure, this research suggested DFDs which reflect functions at single command nodes, distributed command nodes and distributed command nodes with weapon systems.

h). An explicit Module to relate the statics and dynamics of the C2 system together is necessary.

THE SELECTED ARCHITECTURES:
SAC OPERATIONAL TESTING STUDY

OVERVIEW

This study was undertaken by Capt Ingabee Stone, HQ SAC/SICCP, with the cooperation of Mr. Dan Weis of ESI Systems, Incorporated (ESI). ESI is under contract to the Defense Communications Agency to provide a Qualified Operational Test and Evaluation (QOT&E) plan for the Strategic Air Command (SAC). SAC will use the plan to evaluate how well PACER LINK II aircraft do their mission. The PACER LINK II program installs new digital communications systems into the EC-135 fleet.

This study is unclassified. Where classified information would add to the understanding of the problem, references are stated. When the precise description of operational procedures are sensitive, unclassified checklist tasks are described.

MODULE 1: PROBLEM FORMULATION

The Initial Problem Statement:

Find a way to test Post Attack Command Control System (PACCS) operational performance onboard PACER LINK II.

Limit interference with the primary PACCS mission.

Assumptions:

The mod (modification) block systems are the future systems that will be integrated into PACER LINK II. Their QOT&E must also be integrated.

Testing procedures already in effect within the military management scheme are the basis of the QOT&E test plan. These include AFOTEC directives.

Assumptions relative to the actual operational environment (user assumptions) include a working knowledge of the Single Integrated Operations Plan (SIOP) and the flight line level operations that carry out the SIOP.

Level of Decision:

What life cycle phase is the program in?

The PACER LINK II program is officially a Class V upgrade in the operational phase of the WWABNCP program. A Class V mod is a change in equipment to an existing program (in this case, the existing WWABNCP program) including a change in capability.

The PACER LINK II program is, in effect, in a procurement/production status

At this stage of the life cycle, the relevant contractors provide information including program management reviews (PMRs) and the Contractor Deliverable Requirements List (CDRLs) associated with production.

The mod block systems themselves are in various life cycle phases. Systems in the concept development phase are the Nuclear Detection System (NDS) and Advanced Narrowband Digital Voice Transmission (ANDVT) system. Systems in the design phase are Ground Wave Emergency Network (GWEN), Military Satellite Communications (MILSTAR), Miniature Receive Terminal (MRT) for VLF/LF, and the 100KW Transmitter and Dual Trailing Wire Antenna (DTWA) systems for VLF/LF.

Mod block systems in production include Peacekeeper Airborne Launch Control System and the STU III (C2) secure voice phone. In these programs, then, decisions are made at all life cycle phases which affect the PACER LINK II analysis.

At what management level is the decision maker?

The decision maker in this case is at the headquarters staff level. The PACER LINK II program manager, HQ SAC/DOCA, will staff the results of the testing and make recommendations to correct or improve the remainder of the equipment installations. The HQ SAC/DO will act on those recommendations and direct the necessary actions.

Critical Elements To Describe The System Of Interest:

The following questions were formulated for the problem of testing and evaluating the new PACER LINK II C3 system:

What is the concept of operations for the time frame this system is expected to operate? Include the threat assessment which drove the new system development.

Current PACCS operations are described in SACR 55-14 and SACR 55-45. A future concept of operations for a SAC airborne command post is contained in the Preliminary System Operational Concept for the Survivable Enduring Command Center in the 2010 time frame.

What are the stated system specifications, specifically the technical requirements?

The PACER LINK II equipment specifications are contained in the Air Force contract with ESI. First level (B-1) specifications are available from the WWABNCP program manager for the Digital Airborne Intercommunications and Switching System (DAISS), the equipment interface unit (EIU), the electronic switching matrix (ESM), the attendant/maintenance control unit (ACU/MCU), the battle staff and operator subscriber station unit (SSU), the flight crew SSU, and the ground line interface and signalling unit (GLISU).

What is the expected WWABNCP role of the PACCS aircraft as nodes in the new system?

The expected WWABNCP role of PACER LINK II configured aircraft will not change for existing networks. The WWABNCP taskings for the PACCS in these networks are defined in EAP-JCS Vol VII, the Force Management Communications Plan, and the NMCS-DOD Emergency Communications Plan.

The operational concepts of the mod block programs may modify the WWABNCP taskings in the future. There are written SOCs for MILSTAR, GWEN and Peacekeeper.

What is the SAC role assigned to the PACCS within the new system?

The SAC command control functions of the PACCS are contained in SACR 100-7 and SACR 100-20 Vol 1.

What are the limits of the airplane, equipment weight, electro-magnetic interference (EMI), operator, space, etc.?

The EC-135 aircraft is limited to 12 hours flight time without air refueling, and 72 hours with refueling. The power supply is 400Hz. Equipment weight is limited by the amount of fuel (and duration) that can be traded for equipment.

EMI between onboard systems is a serious limitation. It is managed by both equipment design and frequency assignment. The current frequency plan is documented in SACR 100-7.

Presently there are three data operators, two radio operators and two inflight maintenance technicians in the communications compartment. With existing capability and taskings, they are able to handle traffic flow. However, increased data rates or voice network taskings, without automation, could require more operators.

What are typical scenarios and what actions must the operator take in order to do the mission in that scenario?

Typical scenarios are suggested by the SIOP. They can be found in Battle Staff Training Scenarios, GIANT DRILLs, POLO HATs and GLOBAL SHIELD exercises.

Operator actions for the set of tasks required during each scenario are written in checklists, operator reference books and SACR 100-7, Vol I.

MODULE 2: C2 SYSTEM BOUNDING

The elements of the PACER LINK II world, shown in Figure 17, represent the initial boundary of the decision-maker on whose behalf the MCES is employed. These elements are:

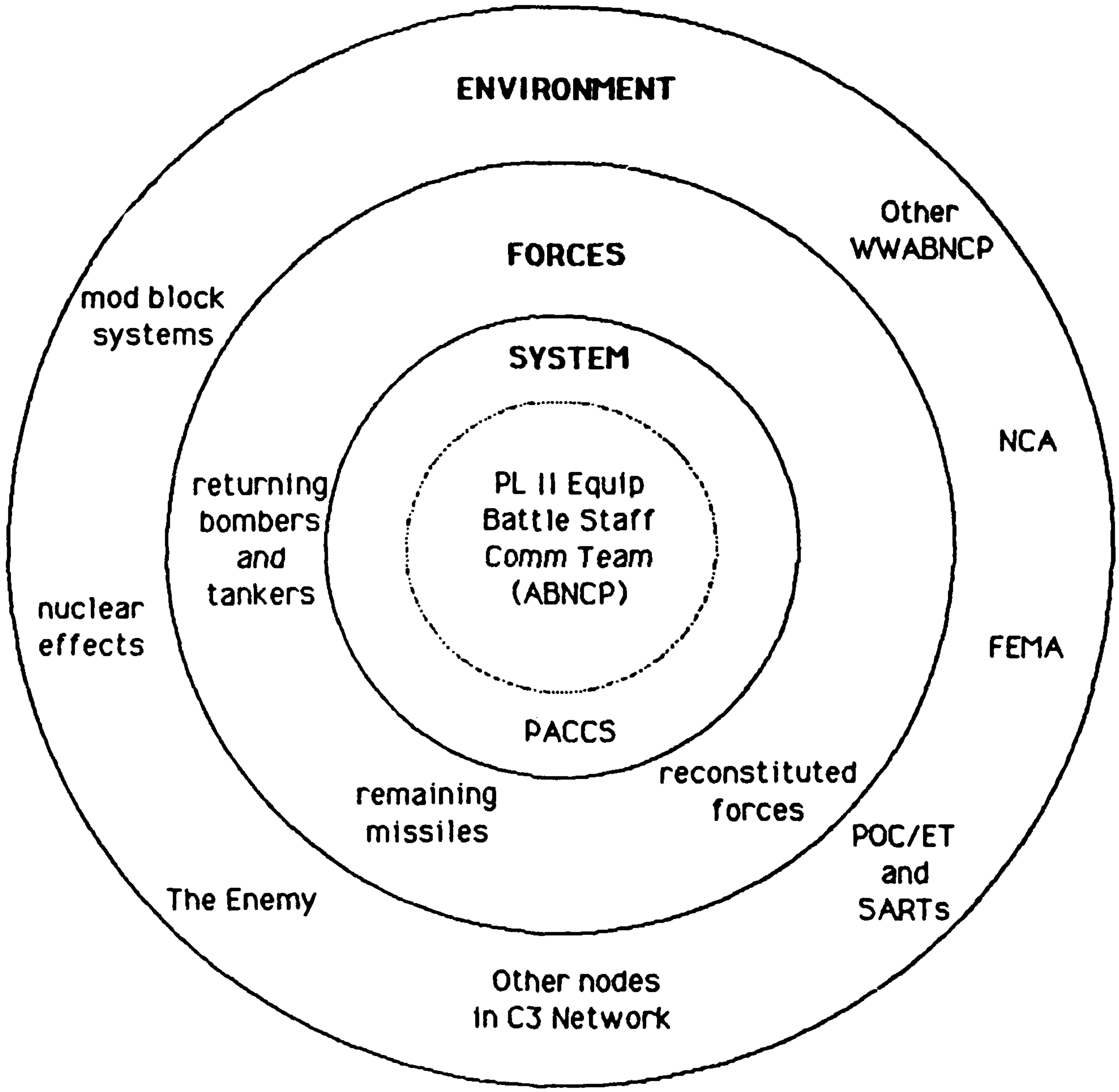


FIGURE 17

SAC OPERATIONAL TESTING STUDY: EXAMPLE OF SYSTEM BOUNDING

PACCS -- the three airborne command post EC-135Cs (ABNCP, EAUXCP, WAUXCP), the three airborne launch control EC-135A/Gs (ALCC-1, ALCC-2, ALCC-3), and the two radio relay EC-135Ls (RR-1, RR-2). An optional member of the PACCS is the CINCSAC alert aircraft, another EC-135C.

PACER LINK II equipment -- the new digital communications equipment installed in the EC-135 fleet.

Battle Staff -- the aircrew members which perform battle staff functions of force status, emergency actions, operations controller, operations planner, intelligence and logistics.

CCO -- the communications control officer.

Comm Team -- the radio operators, data operators and radio maintenance personnel.

ROs -- the radio operators (RO-1 transmits UHF, RO-2 transmits HF).

Other nodes in C3 networks -- Other stations on the ground which relay EAM traffic.

Remaining sensors -- Depending on the post-attack scenario, the NORAD and associated sensors that are accessible using the communications capability provided by PACER LINK II systems.

Returning bombers and tankers -- The SAC aircraft which have completed their mission and are recovering to a surviving base.

Remaining missiles -- Minuteman missiles which have not been launched.

Reconstituted forces -- Aircraft that either did not launch or have returned, and that are refueled, reloaded and have crews ready to launch again, or missiles not yet launched

NCA -- The National Command Authorities or designated successor.

FEMA -- The Federal Emergency Management Agency which maintains connectivity with the NCA.

POC/ET and SARTs -- The ground mobile relocation teams at the SAC headquarters, Numbered Air Forces and units.

Other WWABNCP -- the airborne command posts of the other nuclear SIOP CINCs.

Mod Block Systems -- The upgrade programs for strategic C2 which include the SAC ABNCP as a survivable nod in those systems.

Nuclear effects -- Uncertain but projected to degrade communications for C2 for some time.

The enemy -- the portion of enemy forces who may receive signals from the actions of the PACCS.

An interesting observation can be made at this point. Because of the exhaustive nature of the work in Module 1, the problem was extremely well formulated. Therefore, application of Module 2 becomes straightforward and highly graphically oriented.

It must be noted again and again, that the various steps in the MCES are highly context dependent. Only in rare cases will their execution be of equal difficulty and of equal detail. As the MCES is further tested, some guidelines in this regard will appear. For instance, generic problems will require more detail in formulation and in bounding, since they are still highly conceptual.

Other problems, which are closer to fruition, will probably take more time in specification and aggregation, as their solution are defined and integrated.

MODULE 3: C2 PROCESS DEFINITION

The SAC airborne major functions are: Enduring battle management; Survivable intelligence fusion; and Capabilities planning and force employment support. The SAC airborne C2 functions are shown in Figure 18.

MODULE 4: INTEGRATION OF STATICS AND DYNAMICS

Given the functions which must be performed onboard the SAC ABNCP, this Module identifies which entity (of those described in the C2 Bounding Module) performs which checklist task (of those described in the C2 Process Definition Module).

The following diagrams (Figures 19 and 20) show the integration of a sample task performed by the radio operator and communications control officer to accomplish the C2 function of "Execution". Figure 19 shows the procedural flow of the EAM, within the context of the ABNCP system as it is bounded for this discussion. Figure 20 sets up a matrix that integrates the statics and dynamics.

RECEIVE AND PROCESS TACTICAL WARNING
BRIEF THE NCA
EXECUTION
FORCE DIRECTION
FORCE RECOVERY
FORCE RECONSTRUCTION
FORCE STATUS
RESIDUAL CAPABILITIES ASSESSMENT
TARGET DEVELOPMENT
AIMPOINT CONSTRUCTION
RESTRIKE ORCHESTRATION
WEATHER
RADIATION MONITORING
FALLOUT PREDICTION
STRIKE ASSESSMENT
DAMAGE/ATTACK ASSESSMENT
SITUATION REPORTING
FORCE MANAGEMENT

FIGURE 18

SAC OPERATIONAL TESTING STUDY: SAC AIRBORNE C2 FUNCTIONS

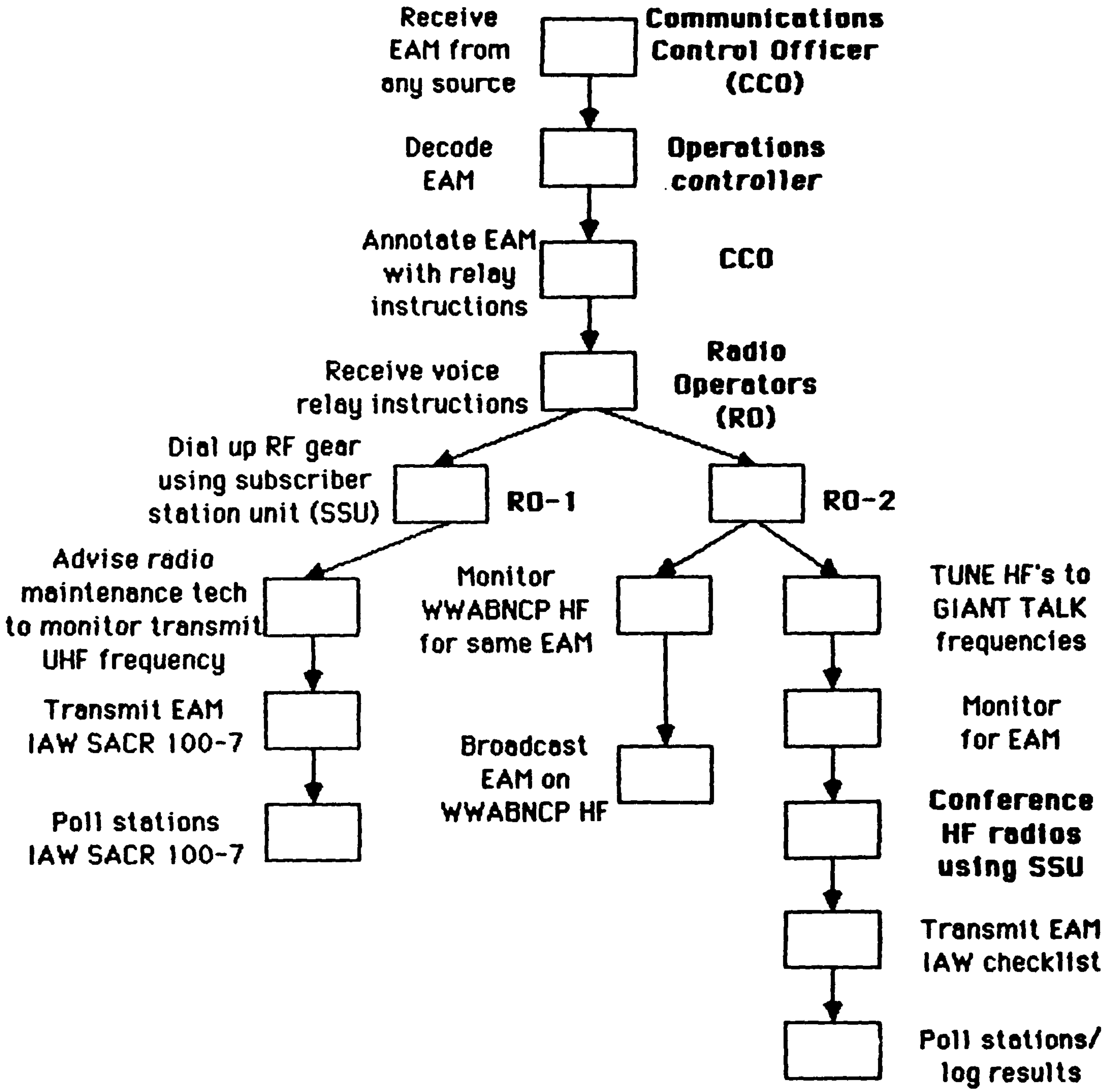


FIGURE 19

SAC OPERATIONAL TESTING STUDY: PROCEDURAL FLOW OF THE EAM

	STATICS		DYNAMICS
	PHYSICAL ENTITIES	STRUCTURE	PROCESS
ELEMENTS	PACER LINK II EQUIPMENT BATTLESTAFF/ COMM TEAM	PROCEDURES (CHECKLISTS)	SENSE ASSESS
SUBSYSTEM	ABNCP	PROCEDURES A/A AND A/G LINKS	SENSE ASSESS
SYSTEM	PACCS	EAM DISSEMINATION FLOW	ASSESS GENERATE PLAN SELECT
ARCHITECTURE	SIOP	EAP-JCS V01 V ROLE	DIRECT

FIGURE 20

SAC OPERATIONAL TESTING: INTEGRATION OF STATICS AND DYNAMICS

Each entity is associated with its position in the C2 organization (or concept of operations) and the generic C2 process functions (sense, assess, generate, plan, select and direct). From these diagrams come the measures which will be specified in the next MCES Module.

The actions taken by each operator to perform this example task, voice relay of an EAM, are documented in SACR 55-45, and crewmember checklists. Procedures for the remaining tasks associated with each C2 function are also contained in those documents. Only one task is shown here in order to preserve the unclassified nature of this paper.

MODULE 5: SPECIFICATION OF MEASURES

Measures may be extracted from the checklist procedures of each crew position. Since this analysis deals with the PACCS as a system and the PACER LINK II equipment as a subsystem, MCES suggests that the appropriate measures are measures of MOEs and MOPs. MOPs in this case are the frequently used measures for communications systems. The operators who collect the measurements, such as noise readings, voice readability, and gain, will compare them to the standard readings associated with the existing aircraft. In this way, they will determine if the capability of PACER LINK aircraft equals that of the non-modified aircraft.

MOEs for this study are similar to those used during POLO HAT evaluations. These measure the connectivity at the system level using the criteria of yes-it-works/no-it-doesn't-work. This is acceptable for this case because the purpose of the Class V modification to the aircraft is to retain the capability of the old aircraft, with only minor additional capability. MOEs for the additional capability are more directly related to the quantified measures of performance previously identified.

Figure 21 summarizes the measures which are applicable to the sample task of voice relay of an EAM. The MOEs are extracted from the ESI QOT&E plan for PACER LINK II aircraft. Although the plan uses the term "MOE" throughout, the figure above indicates which are MOPs and which are MOEs as defined in the MCES.

The MOEs are defined as:

MOE 2.1 The modified communication systems on the PACER LINK modified EC-135 are able to support the operational airborne mission requirements of SAC.

MOE 2.1.3 The DAISS generates, receives, interprets and converts the required analog and digital signaling (control signals).

	STATICS		DYNAMICS
	PHYSICAL ENTITIES	STRUCTURE	PROCESS
ELEMENTS	MOE 2.1		SENSE
SUBSYSTEM			SENSE ASSESS
SYSTEM		MOE 5.1	ASSESS GENERATE PLAN SELECT
ARCHITECTURE		MOE 5.1	DIRECT

FIGURE 21

SAC OPERATIONAL TESTING STUDY: MEASURES OF EFFECTIVENESS

MOE 2.1.10 The DAISS classmarking of the radio operators SSU is functional.

MOE 2.1.32 The radio operator can configure and perform the AM-dropout function.

MOE 2.1.47 The radio operator can conference and perform the HF transmit function.

MOE 5.1 PACER LINK modified EC-135s are interoperable with the ground/airborne resources of the JCS and the unified/specified commands.

MOE 5.1.10 The PACER LINK modified aircraft enables SAC operators to perform their roles as outlined in the EAP-JCS Vol V.

MODULE 6: DATA GENERATION

Data will be generated during a series of test flights designed to simulate the scenarios in which the EC 135 is expected to fly. Onboard each test flight, data will be recorded by highly qualified crew members operating the command and control systems and networks as they would in an operational mission. Data collection logs will approximate real world logs as closely as is feasible.

These test flights will closely follow the POLO HAT scenarios used to evaluate the EC-135 role in strategic command and control.

MODULE 7: AGGREGATION OF MEASURES

This Module of the MCES will analyze the data collected during data generation, aggregate appropriate measures and determine whether this format for testing has demonstrated the operational capability of PACER LINK II aircraft.

FEEDBACK TO THE DECISION MAKER

The product of this iteration of the MCES is a focused, objective QOT&E plan to be used by the PACER LINK II program manager to test and evaluate operations on board the newly configured aircraft.

In this plan, the test and evaluation will be done manually, by observers using checklists and data collection paperwork. Examples drawn from this QOT&E plan are presented.

The entire plan will be delivered to the Defense Communications Agency for SAC at the end of this fiscal year. The insights provided herein, using the MCES, were incorporated by the contractor, ESI, in the overall QOT&E task.

This analysis has been accomplished through the Module 5: Specification of Measures. The remaining Modules will be accomplished when the first PACER LINK II aircraft is delivered to SAC in early 1987.

SUMMARY

The findings of this application were accepted by HQ SAC/DOCA and input to the PACER LINK QOT&E.

Insights derived from the analysis were incorporated by the contractor, ESI, in its overall QOT&E task.

A significant, albeit peripheral, finding from Capt. Stone's work is the vindication of the thesis that a staff officer, new to an assignment, who has been trained in the MCES, may enter the analysis process midstream effectively. Capt. Stone was able to bring herself "up to speed" in her new assignment by using the MCES guidance to focus on the essential components of the volume of materials available to provide background to the PACER LINK QOT&E. As a result, she was able in a relatively short time period, to be a highly productive member of the test team. This spin-off finding has vast training implications to DOD.

This research led to the following lessons learned in regard to the MCES as a tool for evaluating the effectiveness of command and control systems:

(1) MCES can be used to determine the necessary data to be collected in an operational test series to answer the C2 integration problems at hand.

(2) MCES can be effectively applied to a communication system.

(3) This application lead to a series of insights and expansions of the MCES:

a). A standardized set of questions, entitled "Standard Report Format" was developed for Module 1, (See Figure 22.)

b). A graphic representation of selected aspects of system statics was developed, i.e., information flow represented "structure", and platforms were the designated "physical entities".

c). Standard test terminology was shown to be mappable to the MCES terminology, thus expanding the potential commonality of usage of definitions.

<u>The Initial Problem Statement</u>:

<u>Assumptions</u>:

<u>Level of Decision</u>:

What life cycle phase is the program in?

At what management level is the decision maker?

<u>Critical Elements To Describe The System Of Interest</u>:

Problem Specific Questions, e.g.,

1. What is the concept of operations for the time frame in which this system is expected to operate. Include the threat assessment which drove the new system development.

2. What are the stated system specifications, specifically the technical requirements?

3. What is the expected WWABNCP role of the PACCS aircraft as nodes in the new system?

FIGURE 22

STANDARDIZED REPORT FORMAT FOR MODULE 1: PROBLEM FORMULATION

Critical Elements To Describe The System Of Interest: (Cont'd.)

4. What is the SAC role assigned to the PACCS within the new system?

5. What are the limits of the airplane, equipment weight, electro-magnetic interference (EMI), operator, space, etc.?

6. What are typical scenarios and what actions must the operator take in order to do the mission in that scenario?

FIGURE 22 (Concluded)

STANDARDIZED REPORT FORMAT FOR MODULE 1: PROBLEM FORMULATION

THE SELECTED ARCHITECTURES: GLOBAL SCALE WARFARE C2 ARCHITECTURE (SUPERCINC) STUDY

OVERVIEW

This study was undertaken with primary support of the Naval Postgraduate School, OSD and OJCS. Dr. Ricki Sweet was Principal Investigator. Capt. Kevin Briggs was the lead analyst for this research. Dr. Tom Rona provided technical and scientific advise on behalf of OSD. OSD will use this research to provide preliminary scoping of the conceptual development/definition phase of subsequent work on the C2 architectural requirements for SuperCINC. This study is unclassified.

As presented in this report, the SuperCINC problem significantly expands the Air Force Strategic Problem from the Workshop and is a rather detailed scoping for the problem.

MODULE 1: PROBLEM FORMULATION

The Initial Problem Statement:

The initial problem was to develop a command and control concept to exercise operational command responsibility above the CINC level during global-scale warfare operations in the circa 2000 to 2020 timeframe. This concept is herein referred to as SuperCINC.

The SuperCINC command and control doctrine and capability is assumed as necessary to fulfill the role of orchestrating the operational command of global-scale warfare, according to an OSD Memorandum for the Deputy Assistant Secretary of Defense (DASD/C3) titled "Large Scale Challenges to C3I," "At this time, there is no satisfactory concept to provide for the C&C support required to exercise operational command responsibility above the CINC level when operations involve the integrated activities of several CINCs".

"The structure, when fully brought up to the level necessary to satisfy the design objectives, will be adequate to support operations that are essentially circumscribed within the responsibility of individual CINCs. It will not satisfy the operational needs of global-scale warfare (nuclear or other) when these involve operations that transcend the currently defined purviews of the Specified and Unified Commands" (page 6, OSD memorandum).

Assumptions:

1. Operational command refers to those functions of command involving the composition of subordinate forces, the assignment of tasks, the designation of objectives and the authoritative direction necessary to accomplish the mission. It does not include such matters as administration, discipline, internal organization, and unit training except when a subordinate commander requests assistance. (JCS Pub 1)

2. For the purposes of this monograph, global-scale warfare is defined as conventional and/or nuclear operations conducted by the United States, and possibly in concert with its allies, directed concurrently against major enemy forces in more than one unified, specified, or joint task force commander's area of responsibility.

3. A unified command is "a command with a broad continuing mission under a single commander and composed of significant assigned components of two or more Services, and which is established and so designated by the President, through the Secretary of Defense with the advice and assistance of the Joint Chiefs of Staff, or, when so authorized by the Joint Chiefs of Staff, by a

commander of an existing unified command established by the President".(JCS Pub 1)

4. A Joint Task Force (JTF) is a force composed of assigned or attached elements of the Army, the Navy, or the Marine Corps, and the Air Force or two or more of these Services, which is constituted and so designated by the Secretary of Defense or by the commander of a unified command, a specified command, or an existing joint task force. (JCS Pub 1)

Threat: It is plausible that once a major conflict starts in one theater of operations, the United States may face yet another major concurrent conflict in one or more additional geographic regions. Presented below is one such scenario. This scenario is proposed as an unclassified strawman to both exercise the methodology and scope the analysis, the details of which will be classified.

Scenario: There are two components to the scenario, a conventional first phase and a continuation phase during which nuclear war begins.

Scenario Assumptions:

1. SDI systems will be operationally deployed during the circa 2000-2020 timeframe.

2. Current alliance and treaty structures still exist.

Level of Decision:

What life cycle phase is the program in?

This analysis represents the definition phase of the development of an architectural concept for SuperCINC.

At what management level is the decision maker?

This is a mission level analysis. The primary missions of interest for the SuperCINC problem involve deterrence and escalation control.

Critical Elements To Describe The System Of Interest:

Most of the missions of interest involve processes of interaction between the SuperCINC C2 system and the friendly or enemy civil and military leadership/commanders.

Figures 23 and 24 illustrate the systems of interest and some of these interaction missions.

MODULE 2: C2 SYSTEM BOUNDING

The physical entities of the SuperCINC are assumed to consist of the primary and alternate command and control architectures extending to the subordinate CINCs as well as additional C2 architectures (to include doctrines and physical systems) unique to the SuperCINC required to interface with friendly and enemy civil and military leadership.

Although ultimately both procedures and concepts of operation would be described in detail with additional research, the scoping has focused upon the specification of the organizations involved and upon information flow patterns. The organizations involved in the conventional scenario are: NCA, OSD, JCS, NSA, CIA, DIA, NSC, the State Department, CINCEUR/SACEUR, CINCENT, CINCSAC, CINCMAC, CINCRED, and CINCLANT as well as the relevant enemy and friendly civilian and military leadership. For the purposes of discussion, the nuclear scenario participants will also include CINCSPACE, CINCSPACECOM, FEMA, CINCPAC and CINCNORAD.

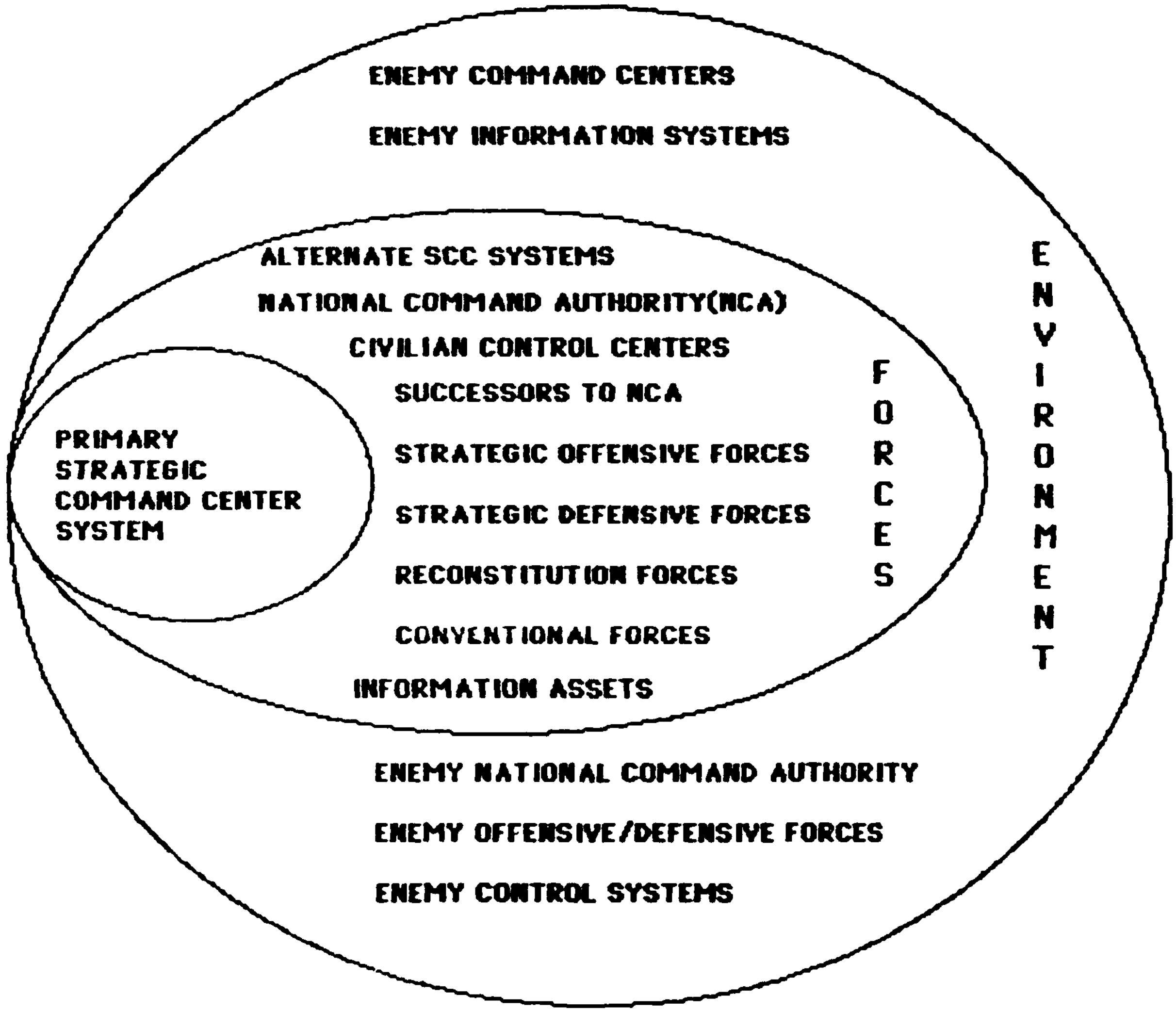


FIGURE 23

GLOBAL SCALE WARFARE C2 ARCHITECTURE (SUPERCINC) STUDY:

SYSTEMS OF INTEREST

INTERACTION SYSTEMS	INTERACTION MISSIONS
NATIONAL COMMAND AUTHORITY (NCA)	ADVISE, SUPPORT, HELP FACILITATE SUCCESSION
STRATEGIC COMMAND CENTER SYSTEM SUCCESSOR	INFORM, MONITOR, EXERCISE, ENABLE
FORCES	DIRECT STRATEGIC OFFENSE DIRECT STRATEGIC DEFENSE
CIVILIAN SECTOR	NOTIFY OF POSTURE CHANGES, SUPPORT
INFORMATION ASSETS	CONTROL, DEFEND
INTERNAL TO PRIMARY SCC SYSTEM	ENDURANCE, DEFEND, GRACEFUL DEGRADATION, ETC
ENEMY NATIONAL COMMAND AUTHORITY	INFLUENCE, MONITOR, INFORM
ENEMY CONTROL SYSTEMS	CONTROL, DECEIVE, DESTROY DISRUPT, MONITOR
ENEMY OFFENSIVE/ DEFENSIVE FORCES INCAPACITATE	DIRECT DESTRUCTION, MONITOR,

FIGURE 24

GLOBAL SCALE WARFARE C2 ARCHITECTURE (SUPERCINC) STUDY:

INTERACTION SYSTEMS AND MISSIONS

MODULE 3: C2 PROCESS DEFINITION

For the purposes of this scoping the internal functions of the generic C2 process are taken as given and the focus is upon: (1) the environmental "initiator" of the C2 processes, which result from a change from the desired state and (2) the input to and output from the internal C2 process. For the environmental initiator, enemy strategy, concepts, tactics, and doctrine in terms of maximizing deterrence and escalation control are pre-cursor requirements for development of SuperCINC capability. For input/output (information flow), a functional perspective is taken.

FEEDBACK TO DECISION MAKER

The remaining Modules are: (1) C2 Process Definition; (2) Integration of Statics and Dynamics; (3) Specification of Measures; (4) Data Generation; and (5) Aggregation of Measures. Therefore, in the strictest sense, feedback to Decision-maker has not been accomplished.

SUMMARY

The SuperCINC problem was carried through the first two Modules of the MCES in some detail. Thereafter, resource constraints were imposed so that subsequent scoping was not possible.

However, the work accomplished represented a firm beginning to analysis of this topic. It is important to note that the Workshop scoping of the Air Force Strategic problem represented approximately 24 man days of effort. The subsequent activity represents approximately 12 additional man days. In general, studies which identify (1) the scenario of interest in the problem, (2) the actors/systems and (3) the information flow require between 5 and 12 man months of effort. Thus, this approach resulted in savings of from 3 to 10 man months.

The SuperCINC analysis as completed will be used in the SDI Workshop mentioned above. It will provide a description of the necessary information flow patterns. In addition, this work will be supportive of the overall SDI concerns with deterrence and escalation control.

The findings of this application were accepted by OSD to provide preliminary problem definition.

This research led to the following lesson learned in regard to the MCES as a tool for evaluating the effectiveness of command and control systems:

> MCES can be used in the conceptual development phase of C2 systems and architectures by providing a top down approach which focuses upon essential elements of the problem.

This application lead to the following insights and expansions of the MCES:

1). There must be a redesignation of Module 1 from its focus on Analysis Objectives to the more global issue of Problem Formulation.

2). Both the assumptions intrinsic to the analysis and the scenario(s) under which the findings will hold must be made explicit.

3). The environmental initiators to the C2 Process must be emphasized.

4). Both the input and the output from the C2 Process must be taken into account.

5). "Plan" may be classified as a "Pre-Real Time" activity.

6). Interoperability issues requires the identification of the actors and systems which make up the architecture of concern.

CONCLUSIONS

The MCES, as developed through the three successive meetings described, has provided the community with a theoretical framework for top level problem specification. It has also provided:

A management support with decision support system to do architectural comparisons;

A systems theory approach to an integrated view of the C2 system/architecture being evaluated;

A vehicle for the integration of disparate tools;

A standard vocabulary which is beginning to be accepted and used within the analytic community;

The guidance for analytic studies. It was this latter role which was exercised in the architectural efforts reported herein.

Testing the MCES in the fire of real world problems dramatically pointed out the strengths of the structure as well as the less well developed aspects.

In some respects, the MCES has yet to reach maturity. In others, these studies have provided an expanded set of imbedded concepts. This section attempts to summarize where the "discipline" of the MCES stands. It should be contrasted with the more generic description presented above.

All of the Modules are important. If measures are to be developed and used, the key Module is Specification of Measures. Everything else is geared to support the relevant set of measures to be developed. In the MCES, the "E" stands for Evaluation, Evaluation through Measurement.

Nevertheless, application studies within the concept development/definition stage are highly dependent on the first four Modules. It is through these Modules that responsibilities are established from the standpoint of organizations working the problem, operational entities using the C2 systems/architectures and agencies participating in program management. Operational studies, including testing, emphasize the last four Modules. Both design and acquisition evaluations are focused primarily in the last three Modules.

In all cases, the first Modules are essential. Preliminary materials representing these early Modules are ideally made available to projects which require them as input.

In those cases, the MCES provides a checklist for the organization of the massive data provided and as an oversight review tool to identify gaps in the information needed to proceed further. Therefore, the MCES is used deferentially to emphasize the appropriate actions needed for the application at hand.

Module 1 describes what the decision-maker's analysis objectives are from the standpoint of (1) the life cycle of a military (C2) system, and (2) the level of analysis prescribed. Both the appropriate scenarios and the assumptions underlying the evaluation are made explicit.

From the standpoint of the life cycle phases, concept development/definition is the focus of the SuperCINC and SDI problems. The design phase is represented by the Navy Battle Group problem. The acquisition phase is not included in this work, although the initial support for this type of standardized analysis approach came from those decision-makers in the community who worked in the acquisition realm. Finally, the operational phase is represented by both the IFFN JTF and the SAC problem. Both of these, of course, are centered upon testing.

The level of the analysis includes only mission (SuperCINC, IFFN, Navy Battle Group, and the SDI problems) and subsystem (SAC) level studies. Figure 25 shows the extent of generalizability of the study results.

For the first Module, the questions given in the software/analyst dialogue example help to clarify the implicit issues involved.

The problem statement is then used in the second Module to bound the C2 system of interest. The definitions used focus upon two parallel relationships. The first shows the system as made up of sub-systems, within a force all of which are within an environment. These define the problem space. Outside the problem space is the "rest of the world". The second shows the elements aggregated to sub-systems, which become systems, which integrate to architectures. The characterization used depends upon the best representation for the problem of interest. In either case, it must reflect both physical entities and structure. This characterization may be exhaustive, covering all aspects of the physical entities and structure, as defined above, or selective of aspects of each, as shown in Figure 26.

None of the studies reported addressed all aspects of these two system statics components. All took a Chinese menu approach.

	MISSION	SYSTEM	SUBSYSTEM
CONCEPT DEVELOPMENT/ DEFINITION	SUPERCINC SDI		
DESIGN	NAVY BATTLE GROUP		
ACQUISITION			
OPERATIONS	IFFN JTF		SAC

FIGURE 25

REPRESENTATIVENESS OF RESEARCH RESULTS

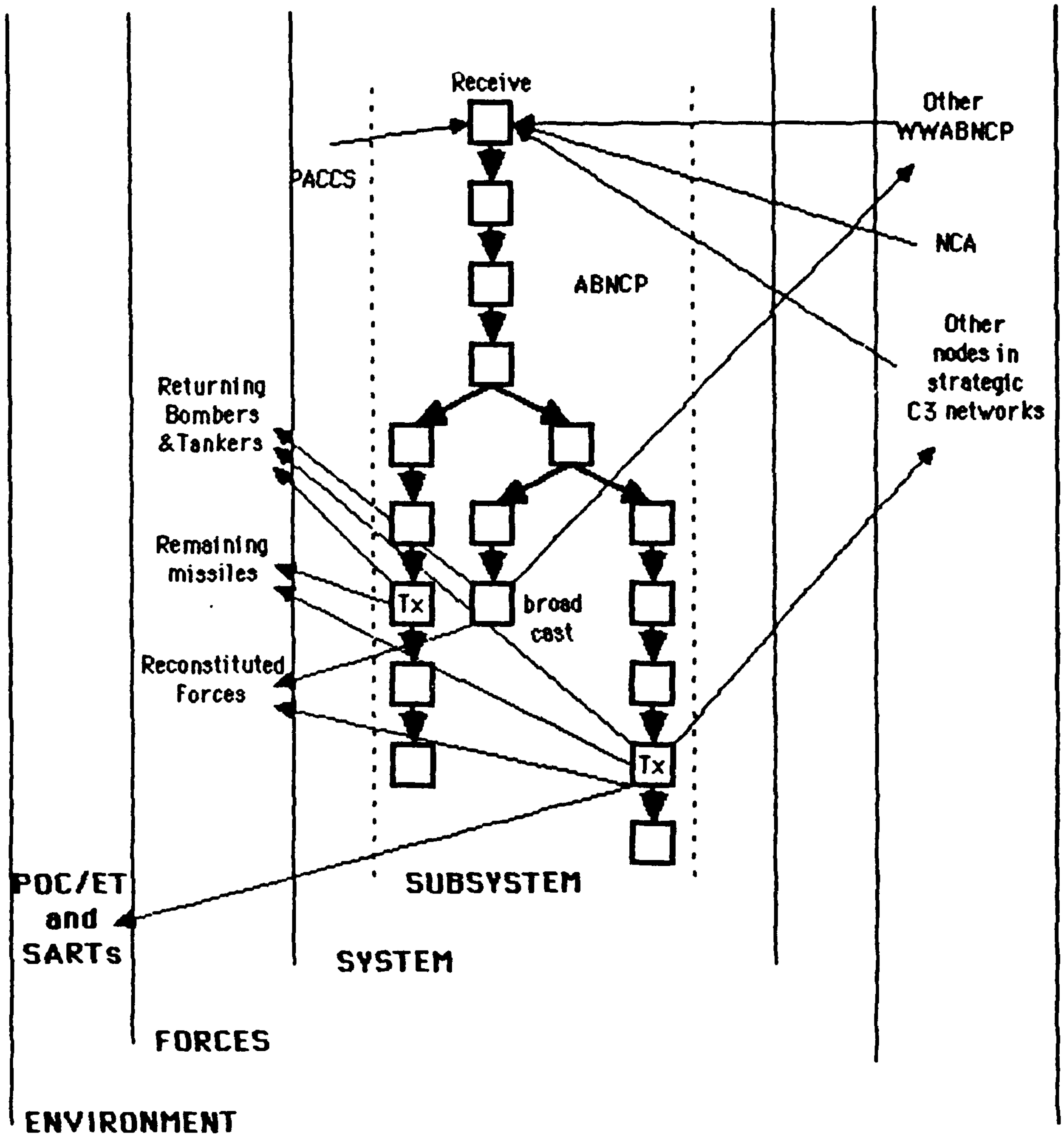


FIGURE 26

EXAMPLE OF SYSTEM STATICS

For the Navy Battle Group problem, physical entities were represented by equipment, whereas structure was represented by organizations. For the IFFN problem, the focus was upon both the equipment and the operational concepts as related to command centers, identification sources, and weapon systems when they perform C2 functions. The SAC problem focussed upon equipment, including facilities as exemplified by platforms, and information flow. The SuperCINC problem defined the physical entities as consisting of the primary and alternate command and control architectures extending to the subordinate CINCs and the structure as involving the specification of the organizations involved and upon information flow patterns. Thus the physical entities - equipment, software, people and their associated facilities, and structure - organization, concepts of operation (including procedures and protocols) and information flow patterns were only marginally represented by these studies, as shown in Figure 27.

The generic C2 process component of the system is applied in the third Module. This concept forces attention on (1) the environmental "initiator" of the C2 process, which result from a change from the desired state; (2) the internal C2 process functions that characterize what the system is doing, (sense, assess, generate, select, plan, and direct); and (3) the input to and output from the internal C2 process.

PHYSICAL ENTITIES				STRUCTURE		
EQUIPMENT	SOFTWARE	PEOPLE	FACIL	ORGANIZATION	CONOPS	INFO FLOW
NBG				NBG		
IFFN					IFFN	
SAC			SAC			SAC
SUPERCINC SUPERCINC				SUPERCINC		

FIGURE 27

C2 SYSTEM BOUNDING: WHAT THE STUDIES INCLUDED

Both the IFFN study and the SuperCINC studies explicitly debated the generic orientation, (2).

The SuperCINC focussed upon the environmental initiator, i.e., primarily the threat to the C2 system which any deficiency represents. In addition, attention was also directed toward the input and output of the C2 process. This was achieved by taking a "black box" approach, similar to that used in communications systems analysis. This proved to be a very useful tool in describing both information flow and transformations.

Both SuperCINC and the IFFN study moved "Plan" from the focus taken by the generic approach. The studies viewed plan as the first activity in the C2 Process. Indeed, plan may be referred to as the "pre-real-time" activity of command and control.

The IFFN study suggested that the C2 Process must be related to other processes at least in a mission level analysis.

The XTEL process was introduced to support sharing of information which occurs on a system level.

The INTEL process indicates that commanders use information from their own sensors, feedback from the forces and interface with a separate intelligence process to develop perceptions about the enemy and friendly capabilities.

This intelligence process also interfaces with the C2 process.

Since the C2 system's purpose is to direct some force within the environment, the process which directly controls weapon systems is defined to be an execution level C2 process.

A separate "force process" is performed by the weapon system and its munitions.

For those studies where the generic approach was taken, the functions of the C2 process for a given problem were identified and mapped to the generic C2 process loop. When this mapping was completed, it embedded the terminology in terms of the canonical six C2 process functions. For those using this approach to the C2 Process, the link to a body of theory relating to C2 Process and its measurement is begun to be made.

The fourth Module relates the C2 processes, physical entities and structure. Techniques such as DFDs and Petri Nets are directed at information flow in the C2 process. A matrix approach has been useful in integrating the three components and relating them to an hierarchical view of systems, i.e. ranging from elements to architectures.

This approach leads more directly to measures that will be descriptive of the C2 system as a whole, whereas considerable interpolation is necessary with both DFD and Petri Nets.

The SuperCINC study ended prior to this Module. The IFFN study employed DFD specifically determining the hierarchical relationships between the individual C2 functions. So used, DFDs reflect an organizational structure, which could reside in a single node or be distributed between command nodes or between command and weapon nodes. Thereafter, the physical entities which perform functions are mapped to the output from the functions. As a result, the IFFN study, with substantial analysis, used DFDs to reflect the integration of the statics and the dynamics of the C2 system/architecture. Indeed, it was this study which first pointed out the requirement in the MCES for such an explicit Module.

The Navy Battle Group study and the SAC study took the matrix approach. The matrix approach, as indicated above, leads to a particular measurement philosophy. The matrix describing the C2 architecture is completed at the appropriate level of detail. One or more measures, suitable to both the problem at hand and the data generator available, are identified. These measures are then taken as the critical or minimum essential set of measures for the problem at hand.

Other techniques, such as Petri Nets, may be employed to derive a complete set of relevant measures, which are then subjected to further scrutiny. These may be compared to a set of criteria measures, reducing the exhaustive set, often in the thousands of measures, to a more manageable set. The IFFN study approach used techniques of this type.

Regardless of the technique chosen, this Module results in the selection of a final set of measures. These may be classified as to their level of measurement, i.e., MOPs, MOEs, or MOFEs, and as a result, to the kind of conclusion that can be drawn using them in an analysis.

The generation of values for these measures is addressed by the next Module. Here, one of several types of data generators is selected. The values to be associated with the measures determined above are the resultant output of the implementation of this Module.

The Navy Battle Group study reported within this report completed its proposal with this Module, although Vol III reports a second study under this funding which included the aggregation Module. The first study employed exercise data for the generation Module, whereas the latter used a simulation model, SCSS, to generate (and aggregate) the values for the measures.

Both the IFFN study and the SAC study will use test data, the former from the testbed and the operational testing study from that environment. For this report, no experiments were used as data generators. All the data generators were selected as available and appropriate to generate the values for the predetermined measures. This flexibility of the MCES to accommodate (or reciprocally to be accommodated by) a variety of data generators was clearly shown in this research effort.

The final Module addresses the issue of how and when to aggregate the measures. The levels of the decisionmaker, his needs and directions for the analysis determine the appropriate format. Such a format may be a set of algorithms, summarizing all the data quantitatively; a matrix of both quantitative and qualitative information; or a description of the results of the analysis, presented in executive summary format. The implementation of this Module provides the analysis results tailored to address the problem initially posed by the decisionmaker, and further qualified in the Problem Formulation Module. Although none of the studies reported herein have directly addressed this issue, it is clear that the level of aggregation, the life cycle of the military system, and the decisionmaker's organizational responsibilities will interact.

It is the opinion of the analysts concerned that this effort has made considerable advances in the realm of the evaluation of C2 systems and architectures. It is with the expectation that the community will judge likewise and will have the interest and need to apply the MCES for his problem area that this document was written.

ACRONYMS

AAW	Anti-Air Warfare
ABNCP	Airborne Command Post
ACU/MCU	Attendant/maintenance control unit
AFOTEC	Air Force Operational Test and Evaluation Center
AF	Air Force
ALCC	Airborne launch control
ANDVT	Advanced Narrowband Digital Voice Transmission system
ASUW	Anti-Surface Warfare
ASUWC	Anti-Surface Warfare Coordinator
ASW	Anti-Submarine Warfare
ATAF	Allied Tactical Air Force (NATO)
BDG	Brigade Fire Detection Center
BFIM	Battle Force Information Management
BM	Battle Management
BNFDC	Battalion Fire Detection Center
BVR	Beyond visual range
CAI	Computer Aided Instruction
C&C	Command and Control
CCO	Communications control officer.
CDRL	Contractor Deliverable Requirements List
CIA	Central Intelligence Agency
CINC	Commander in Chief
CINCENT	Commander in Chief, Central Region (NATO)
CINCEUR	Commander in Chief, U. S. European Command
CINCLANT	Commander in Chief, Atlantic Command
CINCMAC	Commander in Chief, Military Airlift Command
CINCNORAD	Commander in Chief, North American Air Defense Command
CINCPAC	Commander in Chief, Pacific Command
CINCRED	Commander in Chief, U. S. Readiness Command
CINCSAC	Commander in Chief, Strategic Air Command
CINCSPACECOM	Commander in Chief, Aerospace Command
COMSPAWAR	Commander, Space and Warfare Systems Command
CRC	Control and Reporting Center
CRP	Control and Reporting Post
CWC	Composite Warfare Coordinator
C2	Command and Control
C3	Command, Control and Communications
C3CM	C3 countermeasures
C3I	Command, Control, Communications and Intelligence
DAISS	Digital Airborne Intercommunications and Switching System
DASD	Deputy Assistant Secretary of Defense
DFD	Data flow diagrams
DIA	Defense Intelligence Agency
DOD	Department of Defense
DTWA	Dual Trailing Wire Antenna
EAM	Emergency Action Message

EAP	Emergency Action Procedures
EAUXCP	East Auxiliary Airborne Command Post (SAC)
ECM	Electronic Countermeasures
EIU	Equipment interface unit
EMI	Electro-magnetic interference
ESI	ESI Systems, Incorporated
ESM	Electronic switching matrix
EW	Electronic Warfare
EWC	Electronic Warfare Coordinator
FAAD	Forward Area Air Defense
FEMA	Federal Emergency Management Agency
F2D2	Functional flow diagrams and description
GLISU	Ground line interface and signalling unit
GWEN	Ground Wave Emergency Network
HERT	Headquarters Emergency Relocation Team
HF	High Frequency
ICBM	Intercontinental Ballistic Missile
ID	Identification
IFFN	Identification Friend, Foe, or Neutral
INTEL	Intelligence
JCS	OJCS
JDL	Joint Directors of Laboratories
JTC3A	Joint Tactical Command Control and Communications Agency
JTF	Joint Task Force
LD	Launch Detection
LF	Low Frequency
MCES	Modular Command and Control Evaluation Structure
MILSTAR	Military Satellite Communications
MIT	Massachusetts Institute of Technology
mod	Modification
MOE	Measures of Effectiveness
MOFE	Measures of Force Effectiveness
MOP	Measures of Performance
MORS	Military Operations Research Society
MRT	Miniature Receive Terminal
NADC	Naval Air Development Center
NAF	Numbered Air Forces
NAEW	NATO Airborne Early Warning System
NATO	North Atlantic Treaty Organization
NBG	Naval Battle Group
NCA	National Command Authorities
NDS	Nuclear Detection System
NMCS	National Military Command System
NORAD	North American Aerospace Defense Command
NOSC	Naval Ocean System Command
NPS	Naval Postgraduate School
NSA	National Security Agency
NSC	National Security Council
NSWC	Naval Surface Weapons Center
OJCS	Organization of the Joint Chiefs of Staff

ONR	Office of Naval Research
OSD	Office of Secretary of Defense
OSN	Office of the Secretary of the Navy
OTC	Officer in Tactical Command
PACCS	Post Attack Command Control System
PMR	Program management reviews
POC/ET	Proof of Concept, Experimental Testbed
QOT&E	Qualified Operational Test and Evaluation
RO	Radio operators
ROE	Rules of engagement
RR	Radio relay
SAC	Strategic Air Command
SACEUR	Supreme Allied Commander, Europe (NATO)
SACR	Strategic Air Command Regulations
SAM	Surface to air missiles
SCC	Strategic command and control
SCCS	Ship Combat Simulation System
SDI	Space Defense Initiative
SHORAD	Short Range Air Defense
SIOP	Single Integrated Operations Plan
SIS	Special Information System (Intelligence)
SOC	Sector Operations Center
	Statement of Operational Capabilities
SPAWAR	Space and Naval Warfare Systems Command
SSU	Subscriber station unit
TADIL	Tactical Data Information Link
TDS	Tactical data systems
TFCC	Tactical Flag Command Center
TWA	Trailing Wire Antenna
VLF	Very Low Frequency
WWABNCP	World Wide Airborne Command Post
WAUXCP	West Auxiliary Airborne Command Post (SAC)
XTEL	Crosstell